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A TEXTBOOK

ON

STEAM ENGINEERING

INTERNATIONAL CORRESPONDENCE SCHOOLS
SCRANTON, PA.

ELEMENTS OF ELECTRICITY AND MAGNETISM
DYNAMOS AND MOTORS
OPERATION OF DYNAMOS AND MOTORS
HEAT AND STEAM
TYPES OF STEAM BOILERS
BOILER DETAILS
BOILER FITTINGS
COMBUSTION, FIRING, AND DRAFT

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7. In the following list, called the **electric series,** the substances are arranged in such order that each receives a *positive* charge when rubbed or placed in contact with any of the bodies following it, and a *negative* charge when rubbed with any of those which precede it:

1. Fur.
2. Flannel.
3. Ivory.
4. Crystals.
5. Glass.
6. Cotton.
7. Silk.
8. The body.
9. Wood.
10. Metals.
11. Sealing-wax.
12. Resins.
13. Sulphur.
14. Gutta-percha.
15. Guncotton.

For example, *glass* when rubbed with *fur* receives a *negative* charge, but when rubbed with *silk* it receives a *positive* charge.

CONDUCTORS AND NON-CONDUCTORS.

8. Only that part of a dry glass rod which has been rubbed will be electrified; the other parts will produce neither repulsion nor attraction when brought near a suspended pith-ball. The same is true of a piece of sealing-wax or resin. These bodies do not readily *conduct* electricity; that is, they *oppose* or *resist* the passage of electricity through them. Therefore, it can only reside as a *charge* upon that part of their surface where it is developed. Experiments show that when a metal receives a charge at any point, the electricity immediately passes or flows through its substance to all parts. Metals, therefore, are said to be **good conductors** of electricity. Bodies have accordingly been divided into two classes, i. e., **non-conductors,** or **insulators,** or those bodies which offer a very high **resistance** to the passage of electricity, and **conductors,** or those bodies which offer a comparatively low resistance to its passage. This distinction is not absolute, for all bodies conduct electricity to some extent, while there is no known substance which does not offer some resistance to the flow of electricity.

In giving the following list and dividing the different substances into two classes, it should be understood that it is done only as a guide for the student. Between these two classes are many substances which might be included in either list, and no hard or fast line can be drawn.

Silver,	CONDUCTORS.
Copper,	
Other Metals,	
Charcoal,	
Ordinary Water,	
The Body.	
Paper,	NON-CONDUCTORS OR INSULATORS.
Oils,	
Porcelain,	
Wood,	
Silk,	
Resins,	
Gutta-percha,	
Shellac,	
Ebonite,	
Paraffin,	
Glass,	
Dry Air, etc.	

ELECTRODYNAMICS.

9. In dealing with *electric currents*, the word potential will be substituted for the general and vague phrase *electrical condition*.

The term *potential*, as used in electrical science, is analogous with *pressure* in gases, *head* in liquids, and *temperature* in heat.

When an electrified body *positively* charged is connected to the earth by a conductor, electricity is said to flow *from* the body *to* the earth; and, conversely, when an electrified body *negatively* charged is connected to the earth in a similar manner, electricity is said to flow *from* the earth *to* that body. This is called the **direction of flow** of an electric current. That which determines the *direction of flow* is the relative *electrical potential*, or *pressure*, of the two charges in regard to the earth.

It is impossible to say with certainty in which direction electricity really flows, or, in other words, to declare which of two points has the higher and which the lower electrical potential, or pressure. All that can be said with certainty is that when there is a *difference of electrical potential*, or *pressure*, electricity tends to flow *from* the point of higher *to* that of the lower *potential*, or *pressure*.

For convenience, it has been arbitrarily assumed and conventionally adopted that that electrical condition called *positive* is at a higher potential, or pressure, than that called *negative*, and that electricity tends to flow *from* a *positively to* a *negatively* electrified body.

The zero or normal level of water is taken as that of the surface of the sea, and the normal pressure of air and gases as that of the atmosphere at the sea level; similarly, there is a *zero potential*, or *pressure*, *of electricity* in the earth itself. The earth may be regarded as a reservoir of electricity of infinite quantity, and its potential, or pressure, may therefore be taken as zero.

The electrical condition called *positive* is assumed to be at a higher potential, or pressure, than the earth, and that called *negative* is assumed to be at a lower potential, or pressure, than the earth.

10. It must be understood that electricity is a *condition of matter*, and not matter itself, for it possesses neither *weight* nor *dimensions*. Consequently, the statement that electricity is *flowing* through a conductor must not be taken too literally; it must not be supposed that any material substance, such as a liquid, is actually passing through the conductor in the same sense as water flows through a pipe. The statement that electricity is flowing through a conductor is other way of expressing the fact that the conductor and the space surrounding it are in different conditions than usual and that they possess unusual properties. The action of electricity, however, is quite similar in many respects to the flow of liquids, and the study of electric currents is much simplified by the analogy.

11. In order to produce what is called an electric current, *it is first necessary to cause a difference of electrical potential between two bodies or between two parts of the same body.*

It was stated that when two dissimilar substances are simply placed in contact, one always assumes the positive and the other the negative condition; or, in other words, *a difference of electrical potential is developed between the two bodies.*

Placing a piece of copper and zinc in contact will develop a difference of electrical potential which can easily be detected. The same results will follow if the plates are slightly separated from each other and placed in a vessel containing saline or acidulated water, leaving a small portion of one end of each plate exposed. The exposed ends of the zinc and copper are now electrified to different degrees, or, in other words, there is a *difference of electrical potential* between them, one plate being at a higher potential than the other.

When the exposed ends are connected by any conducting material, the potential between the plates tends to *equalize* and a momentary rush or discharge of electricity passes between the exposed ends through the conductor, and also between the submerged ends through the liquid. During its passage through the liquid, the electricity causes certain chemical changes to take place; these chemical changes cause in their turn a fresh *difference of potential* between the plates, which is followed immediately by another equalizing discharge, and that by a further difference, and so on. These changes follow one another with great rapidity—so rapidly, in fact, that it is impossible to distinguish them apart, and they appear absolutely *continuous*. The equalizing flow which is constantly taking place from one plate to the other is known as a **continuous current** of electricity. Consequently, an electric current becomes continuous when the difference of potential is constantly maintained.

By the use of a very delicate instrument, the submerged end of the copper is found to be electrified with a *negative* charge, while the submerged end of the zinc is electrified with a *positive* charge. The direction of the current, therefore, will be *from* the *submerged* end of the zinc through the liquid *to* the *submerged* end of the copper, and *from* the *exposed* end of the copper *to* the *exposed* end of the zinc.

12. A **simple voltaic,** or **galvanic, cell,** Fig. 2, is an apparatus for developing a continuous current of electricity. It consists essentially of a vessel containing saline or acidulated water in which are submerged two plates of dissimilar metals, or one metal and a metalloid (as, for instance, carbon).

Electrolyte is the name given to the liquid, which, as it transmits the current, is decomposed by it.

The two dissimilar metals, when spoken of separately, are called **voltaic,** or **galvanic, elements;** and, when taken collectively, are known as a **voltaic couple.**

A **voltaic,** or **galvanic, battery** is a number of simple cells properly joined together.

Electrodes, or **poles,** of a cell or battery are metallic terminals or connectors attached to the exposed ends of the plates, and are used to connect the cell or battery to any exterior conductor or to another cell or battery.

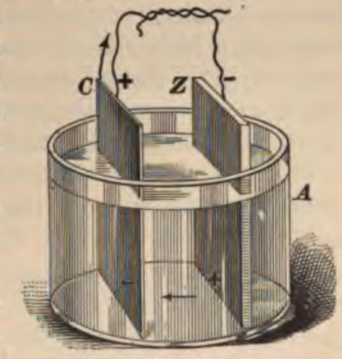


FIG. 2.

It should be remembered that the polarity of the submerged ends of the plates is always of opposite sign to that of their electrodes. For example, in the case of the zinc-and-copper couple, the electrode fastened to the zinc would be spoken of as the *negative* electrode of the cell, while the zinc itself would be the *positive* element of the cell, its submerged end being *positive*.

In any voltaic, or galvanic, couple, the element which is acted upon by the electrolyte will always be the *positive* element and its electrode the *negative* electrode of the cell.

13. The following list of voltaic elements composes what is called the **electromotive series**:

1. Zinc.
2. Cadmium.
3. Tin.
4. Lead.
5. Iron.
6. Nickel.
7. Bismuth.
8. Antimony.
9. Copper.
10. Silver.
11. Gold.
12. Platinum.
13. Graphite.

Any two of these metals form a *voltaic couple* and produce a difference of potential when submerged in saline or acidulated water, the one standing first on the list being the *positive* element or plate, and the other the *negative*. For example, if *nickel* and *graphite* are used, the *nickel* will be acted upon by the liquid and will form the *positive* element; but if *nickel* and *zinc* are used, the *zinc* will be acted upon by the liquid and hence will be the *positive* element.

The difference of potential will be greater in proportion to the distance between the positions of the two substances in the list. For example, the difference of potential developed between *zinc* and *graphite* is much greater than that developed between *zinc* and *nickel*; in fact, the difference of potential developed between zinc and graphite is equal to the difference of potential developed between zinc and nickel *plus* that developed between nickel and graphite.

Electricity flowing as a *current* differs from *static charges* in three important degrees—namely, (1) its *potential* is much lower; (2) its *actual quantity* is greater; and (3) it is *continuous*.

A substance charged from a strong voltaic battery possesses the property of attracting light substances in only the slightest degree; in fact, the attractions can only be detected with the most delicate instruments. The *potential* of a current of electricity is comparatively so small that a voltaic battery composed of a large number of cells is not sufficient to produce a spark more than one or two one-hundredths of an inch long in air, whereas a small, rapidly moving leather belt will sometimes produce static sparks of more than an inch in length. The length of the spark affords a means of estimating potentials, a high potential being capable of producing a longer spark than a low potential; but the length of spark gives us no means of estimating the **current strength** or quantity of electricity flowing. The actual *quantity* of electricity is measured by the amount of water it will decompose. Gauged by this standard, the quantity of electricity produced by a voltaic cell no larger than a thimble would be found greater than that from a large, rapidly moving belt giving static sparks several inches in length.

14. There are three different methods of connecting or grouping the cells in a voltaic battery: *In series; in parallel, or multiple-arc; in multiple-series.*

Cells are connected **in series** when the positive electrode of the first cell is connected to the negative electrode of the second, and the positive electrode of the second is connected to the negative electrode of the third, and so on, as shown in the diagram, Fig. 3. In this we have adopted the usual signs for representing a cell, the short, broad line representing the positive electrode of the cell and the long, narrow line the negative electrode. In this method of connecting or grouping cells, when the negative electrode of the first cell is connected to the positive electrode of the last by some exterior conductor, the total current produced will flow successively through each cell. This method of

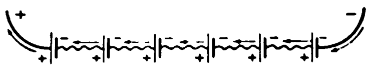


FIG. 3.

grouping is used when there is available a large number of *low*-potential cells and a *high* potential is desired, as in long telegraph lines or any other *high*-resistance circuit.

15. Cells are connected in **parallel,** or **multiple-arc,** when the positive electrodes of all the cells are connected to one main positive conductor and all the negative electrodes are connected to one main negative conductor, as shown by the diagram, Fig. 4. In parallel, or multiple-arc, grouping, only a part of the total current flowing in main conductors will pass through each cell. This method of grouping is used when it is desired to obtain a strong current from a number of cells (when the external resistance is *low*), as in electroplating.

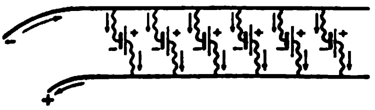


FIG. 4.

16. Cells are connected in **multiple-series** by arranging them in several groups, each group being composed of several cells connected in series, and then connecting all the groups together in parallel, or multiple-arc, as shown in the diagram, Fig. 5. This method is used where both a higher potential and a stronger current are required than any one cell of the group will give.

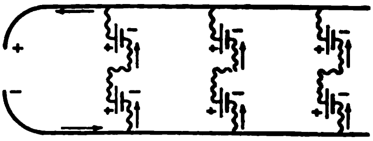


FIG. 5.

CIRCUITS.

17. A **circuit** is a path composed of a conductor or of several conductors joined together, through which an electric current flows from a given point around the conducting path back again to its starting point.

A circuit is **broken,** or **open,** when its conducting elements are disconnected in such manner as to prevent the current from flowing.

A circuit is **closed,** or **complete,** when its conducting elements are so connected as to allow the current to flow.

A circuit in which the earth, or ground, forms part of the conducting path is called an **earth,** or a **grounded,** circuit.

The **external** circuit is that part of a circuit which is outside or external to the electric source.

The **internal** circuit is that part of a circuit which is included within the electric source.

In the case of the simple voltaic cell, the *internal circuit* consists of the two metallic plates, or elements, and the electrolyte; an *external circuit* would be a wire or any conductor connecting the free ends of the electrodes.

18. Conductors are said to be connected **in series** when they are so joined together as to allow the current to pass consecutively through each. For example, Fig. 6 represents a *closed* circuit consisting of a simple voltaic cell *B* and four conductors *a*, *b*, *c*, and *d* connected *in series.*

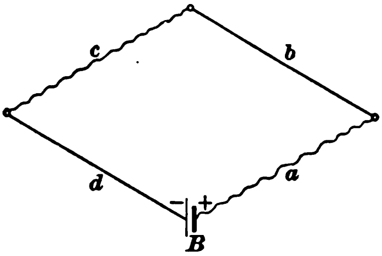


FIG. 6.

A circuit which is divided into two or more branches, each branch transmitting part of the main current, is a **derived, or shunt, circuit,** and the separate branches are said to be connected in **parallel,** or **multiple-arc.** An example of a *derived* circuit of two branches in *parallel* is shown in Fig. 7. The main current flows first through the conductor *a*, then divides between the branches *c* and *b*, and finally unites and completes the circuit through the conductor *d*, the two branches *c* and *b* being the conductors which are connected in *parallel*, or *multiple-arc*. The way the current divides and how the amount which will flow through the branches *b* and *c* is determined will be treated of later.

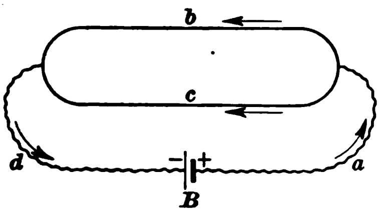


FIG. 7.

MAGNETISM.

19. Magnets are substances which have the property of attracting pieces of iron or steel, and the term **magnetism** is applied to the cause of this attraction. *Magnetism* exists in a natural state in an ore of iron, which is known in chemistry as *magnetic oxide of iron*, or *magnetite*. This magnetic ore was first found by the ancients in *Magnesia*, a city in Asia Minor; hence, substances possessing this property have been called magnets.

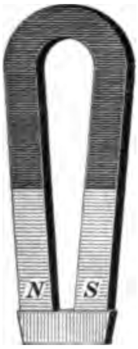


FIG. 8.

It was also discovered that when a small bar of this ore is suspended in a horizontal position by a thread, it has the property of pointing in a north and south direction. From this fact the name **lodestone**—*leading-stone*—was given to the ore.

When a bar or needle of hardened steel is rubbed with a piece of lodestone, it acquires magnetic properties similar to those of the lodestone without the latter losing any of its own force. Such bars are called **artificial** magnets.

Artificial magnets which retain their magnetism for a long time are called **permanent magnets.**

The common form of artificial, or permanent, magnet, Fig. 8, is a bar of steel bent into the shape of a *horseshoe* and then hardened and magnetized. A piece of soft iron, called an **armature**, or a **keeper**, is placed across the two free ends, which helps to prevent the steel from losing its magnetism.

20. If a bar magnet is dipped into iron filings, the filings are attracted toward the two ends and adhere there in tufts, while toward the center of the bar, half way between the two ends, there is no such tendency. (See Fig. 9.) That part of the magnet where there is no apparent magnetic attraction is called the **neutral line**, and [illegible] around the two ends where the attraction is greatest are called **poles**. An imaginary line drawn through the center of the magnet from end to end, connecting the two poles together, is called the **axis of magnetism.**

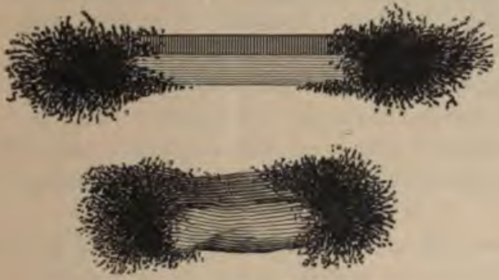


FIG. 9.

A **compass** consists of a magnetized steel needle, Fig. 10, resting upon a fine point, so as to turn freely in a horizontal plane. When not in the vicinity of other magnets or magnetized iron, the needle will always come to rest with one end pointing towards the north and the other towards the south. The end pointing northward is the **north-seeking pole,** or, simply, the *north pole*, and the opposite end is the **south-seeking** or *south pole*. This *polarity* applies as well to all magnets.

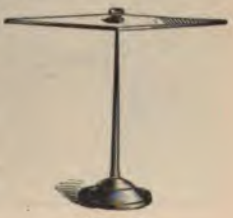


FIG. 10.

If the *north pole* of one magnet is brought near the *south pole* of another magnet, attraction takes place; but if two north poles or two south poles are brought together, they repel each other. In general, *like magnetic poles repel one another; unlike poles attract one another.*

The earth is a great magnet whose magnetic poles coincide nearly, but not quite, with the true geographical north and south poles. A freely suspended magnet, therefore, will always point in an approximately north and south direction.

It is impossible to produce a magnet with only one pole. If a long bar magnet is broken into any number of parts, each part will still be a magnet and have two poles, a north and a south one.

21. Magnetic substances are those substances which, although not in themselves magnets, that is, not possessing poles and neutral lines, are, nevertheless, capable of being attracted by a magnet. In addition to iron and its alloys, the following elements are magnetic substances: *Nickel, cobalt, maganese, oxygen, cerium,* and *chromium.* These, however, possess magnetic properties in a very inferior degree compared with iron and its alloys. All other known substances are called **non-magnetic substances.**

22. The space surrounding a magnet, in which any magnetic substance will be attracted or repelled, is called its **magnetic field,** or, simply, its **field.** Magnetic attractions and repulsions are assumed to act in a definite direction and along imaginary lines called **lines of magnetic force,** or, simply, **lines of force,** and every magnetic field is assumed to be traversed by such *lines of force*—in fact, to exist by virtue of them. Their position in any plane may be shown by placing a sheet of paper over a magnet and sprinkling fine iron filings over the paper. In the case of a bar magnet lying on its side, the iron filings will arrange themselves in curved lines extending from the north to the south pole, as shown in Fig. 11. A view of the magnetic field looking towards either pole of a bar magnet would exhibit merely radial lines, as shown by the filings in Fig. 12.

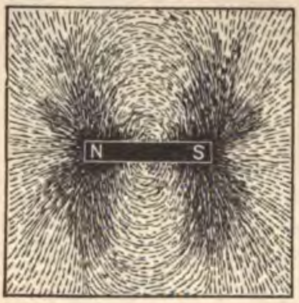


FIG. 11.

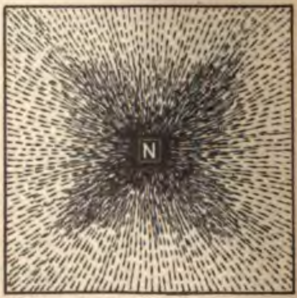


FIG. 12.

Every line of force is assumed to pass out from the north pole, make a complete circuit through the surrounding medium, and pass into the south pole, thence through the magnet to the north pole again, as shown in Fig. 13. This is called the *direction of the lines of force*, and the path which they take is called the *magnetic circuit.*

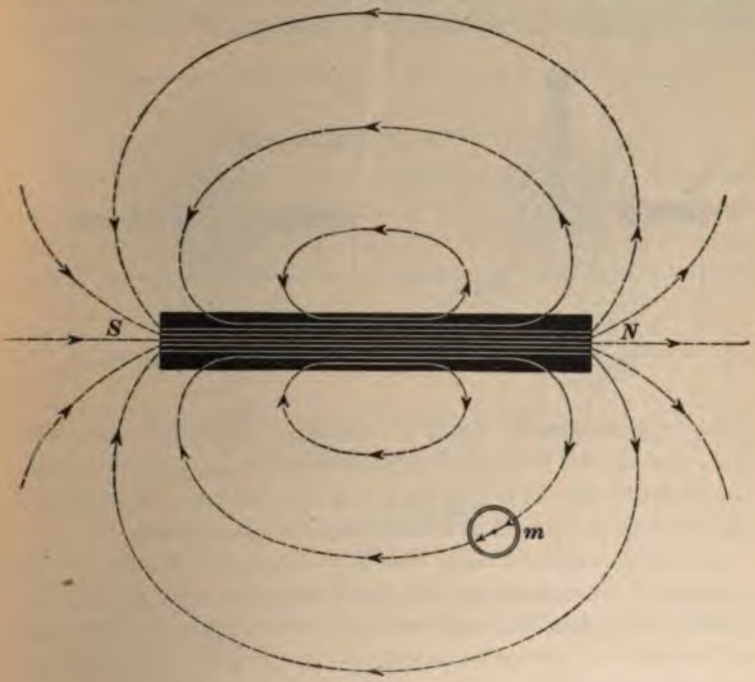


FIG. 13.

23. The *direction of the lines of force* in any magnetic field can be traced by a small, freely suspended magnetic needle, or a small compass such as indicated by *m* in Fig. 13. The north pole of the needle will always point in the direction of the lines of force, the length of the needle lying either parallel or tangent to the lines of force at that point. If the needle be moved bodily in the direction towards which the north pole points, its center or pivot will describe a path coinciding with the direction of the lines of force in that part of the magnetic field.

[illegible] he *direction of the lines of force* will be [illegible] on dotted lines.

Lines of force can never intersect one another; when two opposing magnetic fields are brought together, as indicated by the iron filings in Fig. 14 and Fig. 15, the lines of force from each will be crowded and distorted from their original direction until they coincide in direction with those opposing, and form a resultant field in which the direction of the lines of force will depend upon the relative strengths of the two opposing negative fields. The resulting poles thus formed are called **consequent poles.**

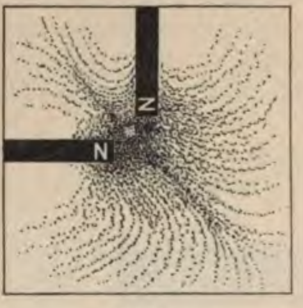


FIG. 14.

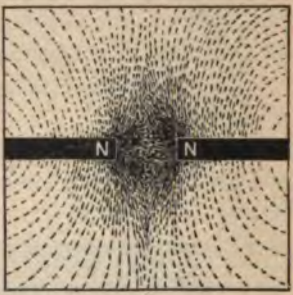


FIG. 15.

In every magnetic field there are certain stresses which produce a *tension* along the lines of force and a *pressure* across them; that is, they tend to *shorten* themselves from end to end and to *repel* one another as they lie side by side.

24. When a magnetic substance is brought into a magnetic field, the lines of force in that vicinity crowd together and all tend to pass through the substance. If the substance is free to move on an axis (but not bodily) towards the magnet pole, it will always come to rest with its greatest extent or length in the direction of the lines of force. The body will then become a magnet, its south pole being situated where the lines of force enter it and its north pole where they pass out. The production of magnetism in a magnetic substance in this manner is called **magnetic induction.** The production of artificial magnetism in a hardened steel needle or bar by contact with lodestone is one case of magnetic induction.

The **amount, or quantity, of magnetism** is expressed by the total number of lines of force contained in a magnetic circuit.

Magnetic density is the number of lines of force passing through a unit area measured perpendicularly to their direction.

ELECTROMAGNETISM.

25. If a conductor be placed parallel to the magnetic axis of a compass needle and a current be passed through the conductor in either direction, the needle will tend to place itself at right angles to the conductor, as shown by arrows in Fig. 16; or, in general, an electric current and a magnet exert a mutual force upon each other. From the definition given in Art. **22,** the space surrounding the conductor is a *magnetic field*. If the conductor is threaded up through a piece of cardboard, and iron filings are sprinkled on the cardboard, they will arrange themselves in concentric circles around the conductor, as represented in Fig. 17. This effect will be observed throughout the entire length of the conductor and is caused entirely by the current. In fact, every conductor conveying a current of electricity can be imagined as completely surrounded by a sort of magnetic *whirl*, the

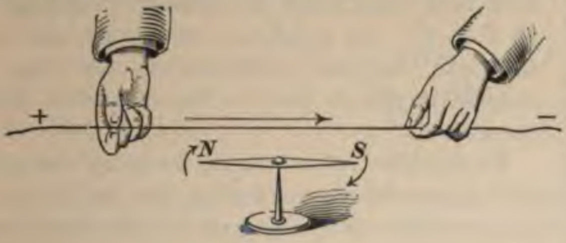


FIG. 16.

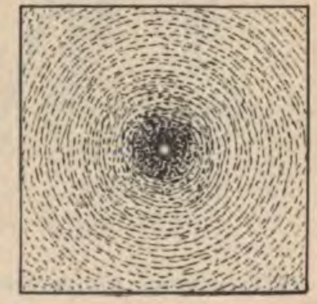


FIG. 17.

magnetic density decreasing as the distance from the current increases. (See Fig. 18.)

26. If the current in a horizontal conductor is flowing *towards* the *north*, and a compass is placed *under* the conductor, Fig. 19, the north pole of the needle will be deflected towards the *west*; by placing the compass *over* the wire, Fig. 20, the north pole of the needle will be deflected towards the *east*. By reversing the direction of the current in the conductor, the needle will point in the opposite direction in each case, respectively.

If the conductor is placed *over* the needle and then bent back *under* it, forming a loop as shown in Fig. 21, the tendency of the current in both top and bottom portions of the wire is to deflect the north pole of the needle in the same direction.

From these experiments, knowing the direction of current in the conductor, the following rule is deduced for the direction of the lines of force around the conductor:

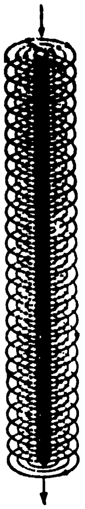


FIG. 18.

Rule.—*If the current is flowing in the conductor away from the observer, then the direction of the lines of force will be around the conductor in the direction of the hands of a watch.*

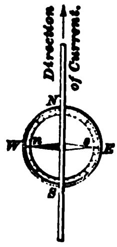


FIG. 19.

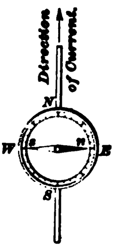


FIG. 20.

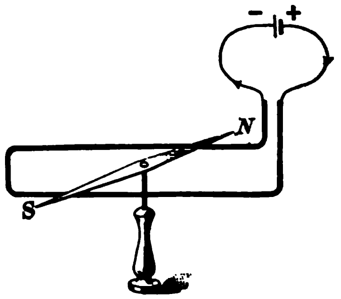


FIG. 21.

The direction of the lines of force around a conductor is indicated in Fig. 22, where the current is assumed to be flowing downwards, that is, piercing the paper.

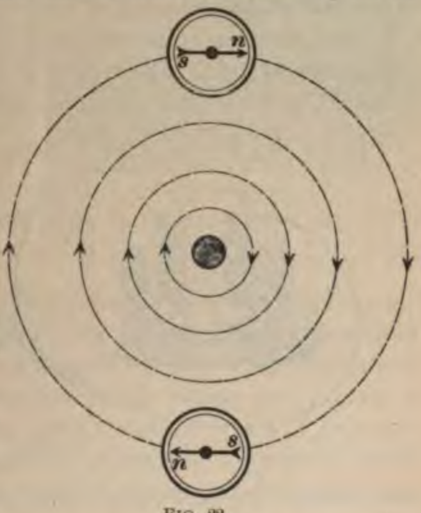


FIG. 22.

27. Two parallel conductors, both transmitting currents of electricity, are either mutually attractive or repellent, depending upon the relative direction of their currents. If the currents are flowing in the *same* direction in both conductors, as represented in Fig. 23, the lines of force will tend to surround both conductors and contract, thus *attracting* the conductors. If, however, the currents are flowing in opposite directions, as in Fig. 24, the lines of force lying between the conductors will have the same direction and therefore *repel* the conductors.

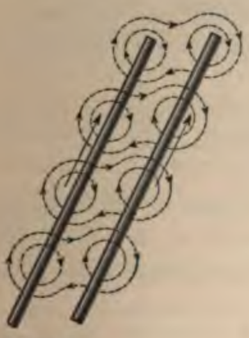


FIG. 23.

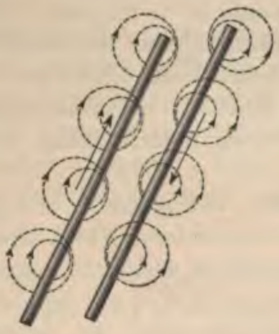


FIG. 24.

28. If the conductor carrying the current is bent into the form of a loop, as in Fig. 25, then all the lines of force around the conductor will thread through the loop in the same direction. By bending the conductor into a long *helix* of several loops, the lines of force around each loop will coincide with those around the adjacent loops, forming several long lines of force which thread through the entire helix, entering at one end and passing out at the other. The same conditions now exist in the helix as exist in a bar magnet, i. e., the lines of force *pass out* from one end and *enter* the other. In fact, the helix possesses a *north* and a *south pole*, a *neutral line*, and all the properties of attraction and repulsion of a magnet. If it is suspended in a horizontal position and free to turn, it will come to rest pointing in a north-and-south direction.

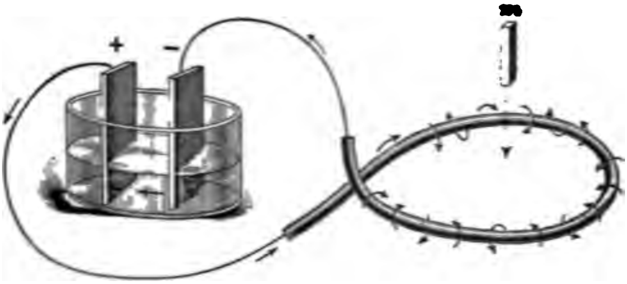


FIG. 25.

A helix made in this manner, around which a current of electricity is circulating, is called a **solenoid.**

29. The **polarity** of a solenoid, that is, the direction of the lines of force which thread through it, depends upon the direction in which the conductor is coiled and the direction of the current in the conductor.

To determine the polarity of a solenoid, knowing the direction of the current:

Rule. *In looking at the end of the helix, if it is so wound that the current circulates around the helix in the direction of the hands of a watch, that end will be a south pole; if in the other direction, it will be a north pole.*

Fig. 26 represents a conductor coiled in a right-handed helix. If the current starts to flow from the end where the observer stands, that end will be a south pole and the observer will be looking through the helix *in the direction of the lines of force.*

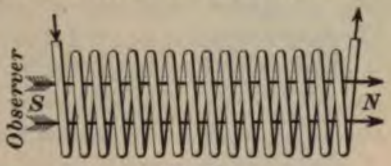


FIG. 26.

The polarity of a solenoid can be changed by reversing the direction of the current in the conductor.

30. It has been stated that when a magnetic substance is brought into a magnetic field, the lines of force in that field crowd together, and all try to pass through that substance; in fact, they will alter their circular shape and extend a considerable distance from their original position in order to pass through it. A magnetic substance, therefore, offers a better path for the lines of force than air or other non-magnetic substances.

The facility afforded by any substance to the passage through it of lines of force is called **magnetic permeability,** or, simply, **permeability.**

The *permeability* of all non-magnetic substances, such as air, copper, wood, etc. is taken as 1, or unity. The permeability of soft iron may be as high as 2,000 times that of air. If, therefore, a piece of soft iron be inserted into the magnetic circuit of a solenoid, the number of lines of force will be greatly increased, and the iron will become highly magnetized.

31. A magnet produced by inserting a magnetic substance into the magnetic circuit of a solenoid is an **electro-magnet,** and the magnetic substance around which the current circulates is called the **core.** (See Fig. 27.) The solenoid is generally termed the **magnetizing coil.**

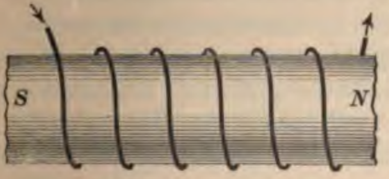


FIG. 27.

In the ordinary form of electromagnet, the magnetizing coil consists of a large number of turns of *insulated* wire, that is, wire covered with a layer or coating of some non-conducting or insulating material, usually silk or cotton; otherwise the current would take a shorter and easier circuit from one coil to the adjacent one or from the first to the last coil through the iron core without circulating around the magnet.

The simplest form of an electromagnet is the bar magnet. As usually constructed, it consists of a straight bar of iron or steel B, fitted into a *spool*, or *bobbin*, made of hard vulcanized rubber or some other inflexible insulating material. The magnetizing coil of fine insulated copper wire w is wound in layers in the bobbin, as shown by the cross-section in Fig. 28.

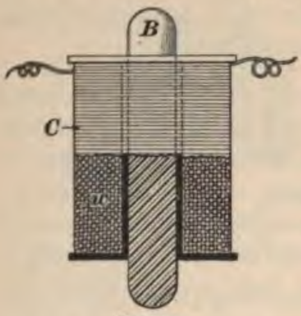


FIG. 28.

The rule for determining the polarity of a solenoid is the same for an electromagnet. It makes no difference whether the wire is wound in one layer or in any number of layers, or whether it is wound towards one end and then wound back again over the previous layer towards the other end; so long as the current circulates continually in the same direction around the core, the polarity of the magnet will remain unchanged.

32. The most convenient form of electromagnet for a great variety of uses is the *horseshoe*, or U-*shaped*, electromagnet, Fig. 30. It consists of a bar of iron bent into the shape of a horseshoe with straight ends and provided with two magnetizing coils, one on each end of the magnet. The two ends which are surrounded by the coils are the *cores* of the magnet, and the arc-shaped piece of iron joining them together is known as the **yoke** of the magnet. The ordinary U-shaped electromagnet is made in three parts, namely, two iron cores wound with the magnetizing coils, and a straight bar of iron joining the two cores together for a yoke, as shown in Fig. 29. In looking at the free ends of the two cores, Fig. 30, the current should circulate around one core in an opposite direction to that around the other. If the current circulates around both cores in the same direction, the lines of force produced in the two cores, respectively, oppose one another, forming two like poles at their free ends and a *consequent pole* in the yoke. The total number of lines of force produced by both coils will be greatly diminished, and the magnet will exhibit only a small amount of magnetic attraction.

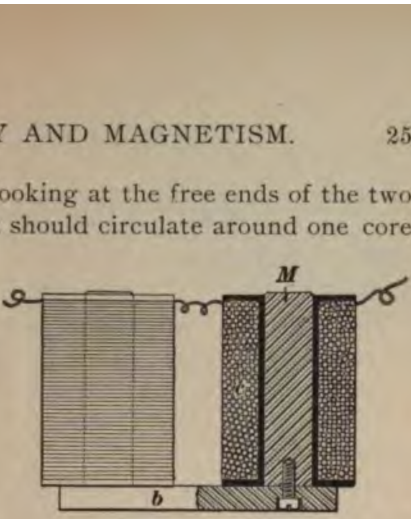


FIG. 29.

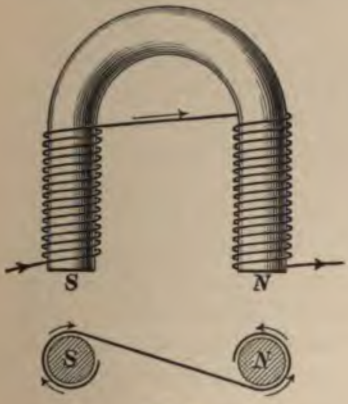


FIG. 30.

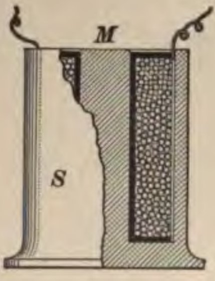


FIG. 31.

Another common form of electromagnet is known as the **iron-clad** electromagnet. In its simplest form, Fig. 31, it contains only one magnetizing coil and one core. The core is fastened to a disk-shaped iron yoke, and the magnetic circuit is completed through an iron shell which rises up from the yoke and completely surrounds and protects the coil.

ELECTRICAL UNITS.

33. The three principal units used in practical measurements of a current of electricity are:

The **ampere,** *or the practical unit denoting the rate of flow of an electric current, or the strength of an electric current.*

The **ohm,** *or the practical unit of resistance.*

The **volt,** *or the practical unit of electrical potential, or pressure.*

Electromotive force, written E. M. F., or simply E., is the *total generated difference of potential* in any electric source or in any circuit. For example, the total difference of potential developed between the plates of a simple voltaic cell would be the *electromotive force* of that cell.

Ordinarily, the term *electromotive force* is used to express any difference of potential between two points.

The relation of these three practical units will be better understood by the analogy of the flow of water through a pipe. The force which causes the water to flow through the pipe is due to the *head*, or *pressure*; that which *resists* the flow is the friction of the water against the inside of the pipe, and the amount will vary with circumstances. The *rate of flow*, or the *current*, may be expressed in *gallons per minute*, and is a ratio between the head, or pressure, and the resistance caused by the friction of the water against the inside of the pipe. For, as the pressure, or head, *increases*, the rate of flow or current *increases* in proportion; as the resistance *increases*, the current *diminishes*.

In the case of electricity flowing through a conductor, the electromotive *force*, or *potential*, corresponds to the pressure, or head, of water, and the resistance which a conductor offers to the flow of electricity to the friction of the water against the [illegible]. The *strength of an electric current*, or the *rate of* [illegible], is also a ratio—the ratio of the electromotive [illegible] the resistance of the conductor through which [illegible] flowing. This ratio as applied to electricity [illegible] by Dr. G. S. Ohm, and has since been

34. Ohm's Law.—*The strength of an electric current in any circuit is directly proportional to the electromotive force developed in that circuit and inversely proportional to the resistance of the circuit;* i. e., *it is equal to the electromotive force divided by the resistance.*

Ohm's law is usually expressed algebraically thus:

$$\text{Strength of current} = \frac{\text{electromotive force}}{\text{resistance}}.$$

If the electromotive force (E) is expressed in *volts* and the resistance (R) in *ohms*, the formula will give the strength of current (C) directly in *amperes;* thus, $C = \frac{E}{R}$.

Before giving examples of the application of Ohm's law, the value and significance of each unit will be treated separately.

35. The Ampere, or the Unit Strength of Current.—The strength of an electric current can be described as a *quantity* of electricity flowing continuously every second, or, in other words, it is the rate of flow of electricity, just as the current expressed in *gallons per minute* is the *rate of flow* of liquids. When one unit quantity of electricity is flowing continuously every second, then the rate of flow, or the strength of current, is *one ampere;* if two unit quantities are flowing continuously every second, then the strength of current is *two amperes*, and so on. It makes no difference in the number of amperes whether the current flows for a long period or for only a fraction of a second; if the quantity of electricity that would flow in one second is the same in both cases, then the strength of the current *in amperes* is the same.

The *international ampere* is defined as the strength of an unvarying current, which, when passed through a solution of nitrate of silver and water, deposits silver at the rate of .01725 grain per second.

Electricity possesses neither *weight* nor *extension*, and therefore an electric current cannot be measured by the usual methods adopted for measuring liquids and gases.

In liquids, the strength of the current is determined by measuring or weighing the actual quantity of the liquid which has passed between two points in a certain time and dividing the result by that time. The strength of an electric current, on the contrary, is determined indirectly by the effect it produces, and the actual quantity of electricity which has passed between two points in a certain time is afterwards calculated by multiplying the strength of the current by the time.

36. The principal effects produced by an electric current are given in Art. **3**; of these, the one most generally used for measuring is the action of the current upon a magnetic needle, as shown in Art. **25.** The instrument commonly used in laboratory practice for measuring and detecting small currents of electricity is called the **galvanometer.**

The action of the galvanometer is based upon the principle given in Art. **25**, where a magnetic needle, freely suspended in the center of a looped or coiled conductor, is deflected by a current of electricity passing around the coil, or loop. In ordinary practice, the needle is suspended either upon a pivot projecting into an agate cup fixed in the needle, or by a fiber suspension, as shown by *F* in Fig. 32. In the simpler forms of galvanometers, the magnetic needle itself swings over a dial graduated in degrees; in other forms, a light index needle is rigidly attached to the magnetic needle and swings over a similar dial, as indicated by *I* in Fig. 32; and in the more sensitive galvanometers, Fig. 33, a small reflecting mirror is attached to the fiber suspension and reflects a beam of light upon a horizontal scale situated several inches from the galvanometer.

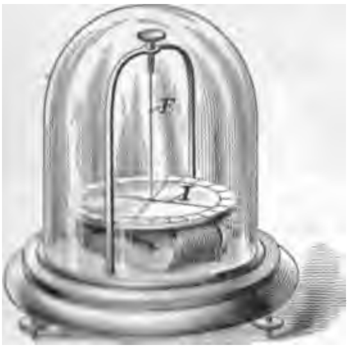


Fig. 32.

In any of these galvanometers, when no current is flowing in the coils, the needle should point in a direction parallel to the length of the coil, Fig. 34. The measuring of currents by most galvanometers depends upon the magnetic needle being held in this position by the magnetic attraction of the earth's magnetism or the attraction of some adjacent magnet. When a current of electricity passes around the coil, its tendency is to deflect the magnetic needle at right angles to its original position, as explained in Art. **25**, while the tendency of the earth's magnetism is to oppose the movement. The couple thereby produced will cause the needle to be deflected a certain number of degrees from its original position, depending upon the relative strengths of the two magnetic fields. The stronger the current in the coil, the greater the deflection. With

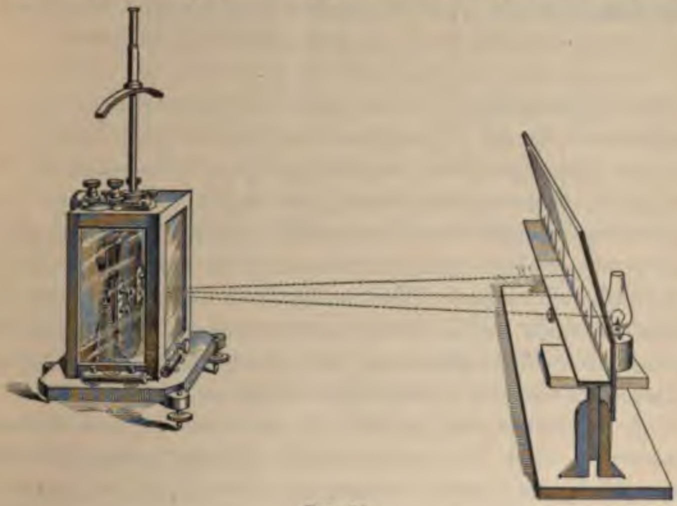


FIG. 33.

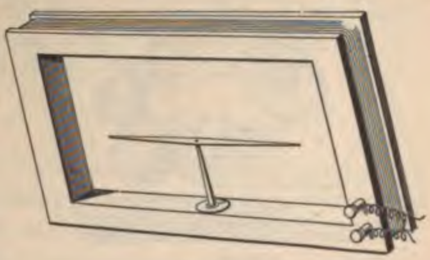


FIG. 34.

galvanometer of standard dimensions and a magnetic field of known strength, such as the earth's magnetism at a convenient place on its surface, a strength of current can be conventionally adopted as a unit which will produce a certain deflection; all other galvanometers can be calibrated from this standard, and their dials graduated to read the strength of current directly in the conventional unit adopted.

37. Commercial and portable instruments are devised for measuring the strength of current directly in *amperes*, and are called **ampere meters**, or simply *ammeters*. The action of the current flowing through the coils in these instruments causes small magnetic needles or other coils of wire to act either against the tension of springs or against gravitational forces. The majority of ammeters are provided with an index needle which travels over a scale or dial graduated in divisions, each division representing one ampere or fractions or multiples of one ampere.

Fig. 35 shows the general form of a standard **Weston ammeter** used for commercial testing purposes. The strength of the current flowing in a circuit can be measured directly in amperes by opening the circuit at any convenient place and connecting the two ends thus formed to the binding post *p* and *p'*. The direction of the current in the circuit should be determined beforehand, so that it passes *into* the instrument by the binding post marked with the positive (+) sign; otherwise the index needle will be deflected off the scale in the wrong direction, which is liable to damage the instrument and cause error in reading when the current passes through in the proper direction.

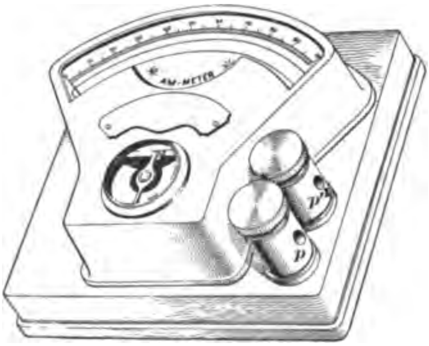


FIG. 35.

38. The Ohm, or the Unit of Resistance.—In Art. **8** it was stated that the resistance varied in different substances; that is, one substance offers a higher resistance to a current of electricity than another. Electrical resistance, therefore, can be defined as a property of matter, varying with different substances, and in virtue of which such matter opposes or resists the passage of electricity.

The resistance which all substances offer to the passage of an electric current is one of the most important quantities in electrical measurements. In the first place, it is that which determines the strength of an electric current in any circuit in which a difference of potential is constantly maintained, as shown by Ohm's law; and in the second place, the unit of resistance, the *ohm*, is the only unit in electrical measurements for which a material standard can be adopted, other quantities being measured by the effect they produce. The basis of any system of physical measurements is generally some material standard conventionally adopted as a unit, physical measurements in each system being made by comparison with the unit of that system.

The unit of electrical resistance now universally adopted is called the **international ohm.** One international ohm is the resistance offered by a column of pure mercury 106.3 centimeters in length and 1 square millimeter in sectional area at 32° F., or the temperature of melting ice. The dimensions of the column expressed in inches are as follows: length, 41.85 inches; sectional area, .00155 square inch. Hereafter the word "international" will be omitted and simply the word "ohm" used; the *international ohm*, however, as defined above, will always be implied unless otherwise stated.

39. If a given conductor offers a resistance of 2 ohms to a current of 1 ampere, it offers the same amount, no more nor less, to a current of 10 amperes. Hence, *the resistance of a given conductor at equal temperatures is always constant, irrespective of the strength of current flowing through it or the electromotive force of the current.*

40. If the length of a conductor be doubled, its resistance will be doubled; that is, the resistance of a given conductor increases as the length of the conductor increases, the resistance being directly proportional to the length of the conductor.

When it is required to find the resistance of a conductor of which the length is varied, and other conditions remain unchanged, the following formula may be used:

$$r_2 = \frac{r_1 l_2}{l_1}. \qquad (1.)$$

In this formula

r_1 = the original resistance;
r_2 = the required or changed resistance;
l_1 = the original length;
l_2 = the changed length.

As in all examples of proportion, the two lengths must be reduced to the same unit.

By this formula, we see that *the resistance of a conductor after its length is changed is equal to the original resistance multiplied by the changed length, and the product divided by the original length.*

EXAMPLE.—Find the resistance of 1 mile of copper wire, if the resistance of 10 feet of the same wire be .013 ohm.

SOLUTION.— $r_1 = .013$ ohm; $l_1 = 10$ feet; $l_2 = 1$ mile $= 5,280$ feet. Then, by formula **1**, the required resistance

$$r_2 = \frac{.013 \times 5,280}{10} = 6.864 \text{ ohms. Ans.}$$

41. If the sectional area of a conductor is doubled and other conditions remain unchanged, the resistance will be halved. We may, then, obtain the value of the resistance of a conductor for any change in sectional area by the following formula:

$$r_2 = \frac{r_1 a_1}{a_2}, \qquad (2.)$$

in which r_1 = the original resistance of the conductor;
r_2 = the changed resistance;
a_1 = the original sectional area;
a_2 = the changed sectional area.

From the relations here expressed, it will be seen that the resistance varies inversely as the sectional area; that is, *the resistance of a given conductor diminishes as its sectional area increases.*

The resistance of a conductor is independent of the *shape* of its cross-section. For example, this shape may be circular, square, rectangular, or irregular; if the sectional area be the same in all cases, the resistances will be the same, other conditions being similar.

EXAMPLE.—The resistance of a conductor whose sectional area is .025 sq. in. is .32 ohm; what would be the resistance of the conductor if its sectional area were increased to .125 sq. in. and other conditions remain unchanged?

SOLUTION.— $r_1 = .32$ ohm; $a_1 = .025$ sq. in.; and $a_2 = .125$ sq. in. Then, by formula **2**, the required resistance

$$r_2 = \frac{r_1 a_1}{a_2} = \frac{.32 \times .025}{.125} = .064 \text{ ohm.} \quad \text{Ans.}$$

EXAMPLE.—The sectional area of a certain conductor is .01 sq. in. and its resistance is 1 ohm; if its sectional area be decreased to .001 sq. in. and other conditions remain unchanged, what will be the resistance?

SOLUTION.— $r_1 = 1$ ohm; $a_1 = .01$ sq. in., and $a_2 = .001$ sq. in. By formula **2**, the resistance

$$r_2 = \frac{1 \times .01}{.001} = 10 \text{ ohms.} \quad \text{Ans.}$$

42. When comparing resistances of round copper wires the following formula is used:

$$r_2 = \frac{r_1 D^2}{d^2}, \qquad (3.)$$

in which r_1 = the original or known resistance;
r_2 = the required resistance;
D = the original diameter;
d = the changed diameter.

This formula is based on the rule that, since the sectional area of a round conductor is proportional to the square of its diameter (sectional area = diameter^2 × .7854), *the resistance of a round conductor is inversely proportional to the square of its diameter.*

EXAMPLE.—The resistance of a round copper wire .2 in. in diameter is 45 ohms; from this calculate the resistance of a round copper wire .3 in. in diameter, other conditions remaining the same in both cases.

SOLUTION.—In this example, r_1 = 45 ohms; D = .2 inch; and d = .3 inch. Hence, by formula **3,** the required resistance

$$r_2 = \frac{45 \times .2^2}{.3^2} = \frac{45 \times .04}{.09} = 20 \text{ ohms. Ans.}$$

EXAMPLE.—If the resistance of a round German-silver wire $\frac{1}{8}$ in. in diameter is 12.6 ohms, what is the resistance of a round German-silver wire $\frac{1}{16}$ in. in diameter, other conditions being equal in the two cases?

SOLUTION.—In this example, r_1 = 12.6 ohms; $D = \frac{1}{8}$ = .125 inch; and $d = \frac{1}{16}$ = .0625 inch. Hence, by formula **3,**

$$r_2 = \frac{12.6 \times .125^2}{.0625^2} = 50.4 \text{ ohms. Ans.}$$

43. The resistance of two or more conductors connected in *series* (Art. **14**) is equal to the sum of their separate resistances. For example, if four conductors having separate resistances of 8, 12, 22, and 34 ohms, respectively, are connected in series, their total or joint resistance would be 8 + 12 + 22 + 34 = 76 ohms.

44. The **microhm** is a unit of resistance devised to facilitate calculations and measurements of exceedingly small resistances, and is equal to *one millionth* $\left(\frac{1}{1,000,000}\right)$ of an *ohm.* Hence, to express the resistance in *microhms*, multiply the resistance in *ohms* by 1,000,000; and, conversely, to express the resistance in *ohms*, divide the resistance in *microhms* by 1,000,000. For example, .75 ohm = .75 × 1,000,000 = 750,000 microhms; or, 750,000 microhms = 750,000 ÷ 1,000,000 = .75 ohm.

45. The **megohm** is a unit of resistance devised to facilitate calculations and measurements of exceedingly large resistances, and is equal to 1,000,000 ohms. Therefore, to express the resistance in *megohms*, divide the resistance in *ohms* by 1,000,000; and, conversely, to express the resistance in *ohms*, multiply the resistance in *megohms* by 1,000,000. For example, 850,000 ohms $= \frac{850,000}{1,000,000} = .85$ megohm; or, .85 megohm $= .85 \times 1,000,000 = 850,000$ ohms. The megohm is used chiefly to measure the resistance of bad conductors and insulators.

46. In order to compare the resistances of different substances, the dimensions of the pieces to be measured must be equal; for, by changing its dimensions, a good conductor may be made to offer the same resistance as an inferior one. Under like conditions, annealed silver offers the least resistance of all known substances. Soft, annealed copper comes next on the list, and then follow all other metals and conductors.

The resistance of a given conductor, however, is not always constant; it changes with the temperature of the conductor. In all metals, the resistance *increases* as the temperature rises; in liquids and carbons, the resistance *decreases* as the temperature rises. The amount of variations in the resistance caused by a change in temperature of one degree is called the **temperature coefficient.** The temperature coefficients for the common metals are given in Table I for degrees Fahrenheit. These coefficients, however, only hold true for a limited change of temperature, and should not be used with extreme changes. The rules given below, making use of these coefficients, are not absolutely accurate, but enough so for practical purposes. To be strictly correct, the quantity r_1 in formula **4** below should, in each case, represent the resistance at the freezing point.

To find the resistance of a conductor after its temperature has risen, knowing its original resistance and the number of degrees rise, other conditions remaining unchanged:

Let r_1 = the original resistance;
r_2 = the resistance after a change in temperature;
k = the temperature coefficient;
t = rise or fall in temperature, degrees Fahrenheit.

Then, for a *rise* in temperature,

$$r_2 = r_1\,(1 + t\,k). \qquad (4.)$$

That is, *the resistance of a conductor after its temperature has risen may be obtained by multiplying the original resistance by 1 plus the product of the number of degrees rise and the temperature coefficient.*

Example.—The resistance of a piece of copper wire at 32° F. is 40 ohms; determine its resistance when its temperature is 52° F.

Solution.—
$R = 40$ ohms;
$k = .002155$ (from Table I);
$t = 52 - 32 = 20$ degrees.

By formula **4**, the required resistance

$r_2 = r_1\,(1 + t\,k) = 40\,(1 + 20 \times .002155) = 40 \times 1.0431 = 41.724$ ohms. Ans.

47. To find the resistance of a conductor after its temperature has fallen, knowing its original resistance and the number of degrees fall, other conditions remaining unchanged:

For a *fall* in temperature, $r_2 = \dfrac{r_1}{1 + t\,k}$. (**5.**)

That is, *the resistance of a conductor after its temperature has fallen may be obtained by dividing the original resistance by one plus the product of the number of degrees fall and the temperature coefficient.*

Example.—The original resistance of a piece of German-silver wire is 16 ohms; find its resistance after its temperature has fallen 22° F.

Solution.—
$R = 16$ ohms;
$k = .000244$ (from Table I);
$t = 22°$ F.

By formula **5**, the required resistance

$r_2 = \dfrac{r_1}{1 + t\,k} = \dfrac{16}{1 + 22 \times .000244} = \dfrac{16}{1.005368} = 15.9145$ ohms. Ans.

48. Specific resistance is the term given to the resistance of substances of unit length and unit sectional area at some standard temperature. In what follows, the specific resistance of a substance is the resistance of a piece of that substance 1 inch in length and 1 square inch in sectional area at 32° F., that is, at the temperature of melting ice; this may also be expressed as the resistance of a cube of that substance taken between two opposing faces.

A list of the common metals is given in Table I, in the order of their relative resistances, beginning with silver, which offers the least resistance. The first column of figures gives the *specific resistance*, in microhms, of 1 cubic inch of the corresponding metal at 32° F. By applying formula **1**, the resistance of any conductor of known dimensions which is made of one of the metals in the table can be determined. The second column of figures gives the relative resistance of the different metals compared with silver. For example,

TABLE I.

Name of Metal.	Resistance, Microhms per Cu. In.	Relative Resistance.	Temperature Coefficient.
Silver, annealed	.5921	1.000	.002094
Copper, annealed	.6292	1.063	.002155
Silver, hard-drawn	.6433	1.086	.002094
Copper, hard-drawn	.6433	1.086	.002155
Gold, annealed	.8102	1.369	.002028
Gold, hard-drawn	.8247	1.393	.002028
Aluminum, annealed	1.1470	1.935	
Zinc, pressed	2.2150	3.741	.002028
Platinum, annealed	3.5650	6.022	
Iron, annealed	3.8250	6.460	
Nickel, annealed	4.9070	8.285	
Tin, pressed	5.2020	8.784	.002028
Lead, pressed	7.7280	13.050	.002150
German Silver	8.2400	13.920	.000244
Antimony, pressed	13.9800	23.600	.002161
Mercury	37.1500	62.730	.000400
Bismuth, pressed	51.6500	87.230	.001967

the resistance of mercury is 62.73 times the resistance of silver, or the resistance of iron is 6.46 times the resistance of silver, and so on.

Example.—Find the resistance in ohms of a round column of mercury 70" high and 0.5" in diameter. Ans. 1.3244 ohms.

Example.—Find the resistance in ohms of 1 mile of square iron wire (annealed) .1" on a side. Ans. 24.2352 ohms.

49. In a simple voltaic cell, the *internal* resistance—that is, the resistance of the two plates and the electrolyte—is of great importance, for it determines the maximum strength of current that can possibly be obtained from the cell. In the common forms of cells, the internal resistance may be excessively large, owing to the resistance of the electrolyte, the specific resistance of ordinary liquids used as electrolytes being from 1 to 20 million times that of the common metals. In liquids, as in all conductors, the resistance increases as the length of the circuit increases, and diminishes as its sectional area increases. Hence, the internal resistance of a simple voltaic cell is reduced by decreasing the distance between the plates or elements and by increasing their active surfaces. The internal resistance of the ordinary forms of cells varies from about .2 to 20 ohms.

50. For practical and commercial testing, the standard column of mercury, representing the resistance of 1 ohm, has been replaced by a coil of wire, usually a platinum-silver alloy. The coil is carefully calibrated to offer a resistance of exactly 1 ohm at some convenient temperature, and is enclosed in a metallic case, the connections to the two ends of the coils being made by two heavy terminals of copper wire passing up through the hard-rubber cover. Such coils are known as *standard*

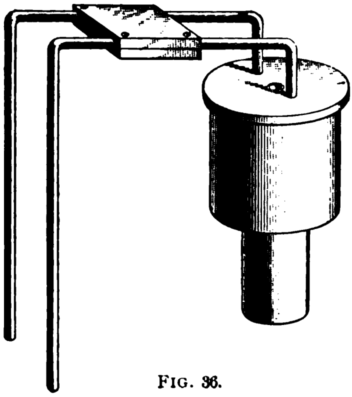


Fig. 36.

ohm coils. The commercial form of standard ohm coils is shown in Fig. 36.

51. A device called a **resistance box** or **rheostat** is largely used for reducing or controlling the strength of currents in various circuits. Such rheostats are connected directly in *series* or *shunt* with the circuit, and are termed *dead resistances*. The resistance in these rheostats is usually made adjustable; that is, the amount of resistance which they offer may be varied at the will of the operator by the use of a sliding contact or by removable plugs. Rheostats in which the amount of resistance is varied by sliding contacts are used mostly where accuracy is of less importance and where the currents are comparatively large.

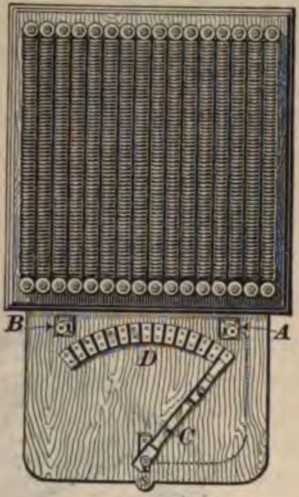


FIG. 37.

Fig. 37 shows a typical form of sliding-contact rheostat. In this particular rheostat, the coils of resistance wire are connected to a row of contact pieces *D*, as shown in the diagram, Fig. 38. The current enters the rheostat through the terminal *A*, passes through the movable arm *C*, and then through all the resistance coils between the contact piece on which the arm rests and the terminal *B*. When the arm rests upon the first contact piece, as shown by the full lines in this diagram, all the resistance is said to be *in circuit;* that is, the current passes through all the

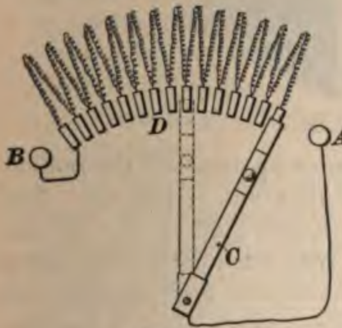


FIG. 38.

coils. By moving the arm to the left, towards the terminal *B*, as shown by the dotted lines, the coils connected to the contact pieces which have been passed over by the arm are said to be *cut out* of circuit, and the current passes through the remaining coils only.

52. Rheostats in which the resistance is adjusted by means of removable plugs are employed in laboratory practice, where small currents are used and where great accuracy is required. The resistance coils in these rheostats are enclosed in a wooden box, and the actual resistance of each coil is carefully determined. A resistance box offering 10,000 ohms resistance is shown in Fig. 39, the separate coils offering resistances from 1 ohm up to 5,000 ohms. The operation of adjusting the resistance by means of the removable plugs can be seen from the diagram in Fig. 40. The contact pieces *a*, *b*, *c*, etc. are arranged side by side on the top of the case and are separated from one another by a small air space. The ends of each contact piece are provided with a tapered recess in such a manner as to allow a metallic plug to be inserted between them and thereby connect the two together electrically. The current passes into the rheostat by the terminal *A*, and when all the plugs are

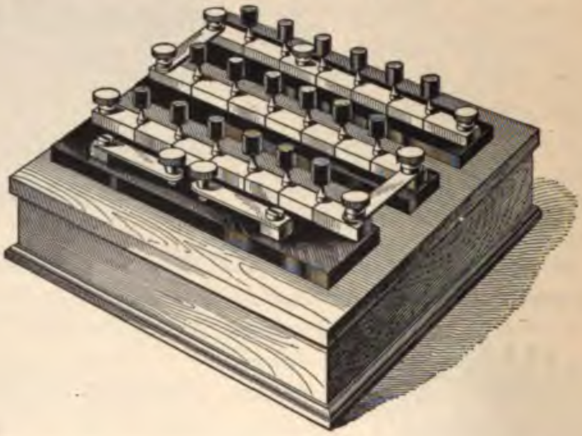


FIG. 39.

removed flows consecutively through all the coils *1*, *2*, *3*, *4*, *5*, and *6* to the terminal *B*. The total resistance of the rheostat can be lowered by inserting the plug *P* between the contact pieces; this operation *short-circuits*, or *cuts out*, the particular coil connected to the two contact pieces, or, in other words, the current, instead of flowing through the coils, passes directly from one contact piece to the other through the metallic plug.

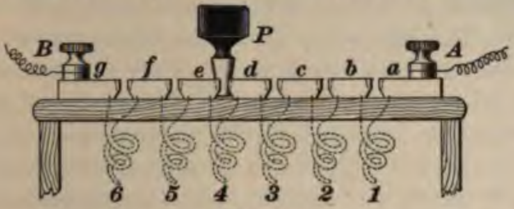


FIG. 40.

53. Electrical resistance may be measured by an apparatus called a **Wheatstone bridge.** A bridge, when completed, ready for taking measurements, consists of three main parts: (1) an adjustable resistance box containing a number of coils, the exact resistance of each coil being known; (2) a galvanometer for detecting small currents; and (3) a battery of several cells. The coils of the resistance box are divided into three groups, two of which are called **proportional** or **balance arms,** and the third is known as the **adjustable arm.** Each proportional arm is composed of three and sometimes four coils of 1, 10, 100, and 1,000 ohms resistance, respectively. The adjustable arm contains a large number of coils ranging from .1 ohm up to 10,000 ohms.

The operation of the bridge depends upon the principle of the relative difference of potential between two points in a divided circuit of two branches. The electrical connections of the bridge are shown in the diagram, Fig. 41. *M* represents the resistance of one of the balance arms, which will be termed for convenience the *upper* balance arm; *N* represents the resistance of the other balance arm, which will be termed the *lower* balance arm; *P* represents the resistance of the adjustable arm, and X represents an unknown resistance, the value of which is to be determined. One terminal of the detecting galvanometer G is connected at c, the junction of the upper balance arm and the unknown resistance; the other terminal is connected at d, the junction of the lower balance arm and the adjustable arm. One pole of the battery is connected at a, the junction of the two balance arms; the other pole at b, the junction of the adjustable resistance and the unknown resistance. The current from the battery divides at a, part of it flowing through resistances M and X, and the rest through N and P. When the resistances M, N, P, and X fulfil the proportion $\frac{M}{N} = \frac{X}{P}$, then the two points c and d will have the same potential, and no current will flow through the galvanometer G. Since the resistances of M, N, and P are known, the resistance of X will be given by the fundamental equation $X = \frac{M}{N} \times P$, when the arms are so adjusted as to cause no deflection of the galvanometer. For example, suppose that the two ends of a copper wire are connected to the terminals b and c, and after adjusting the resistance in the arm so that the galvanometer shows no deflection, the resistances of the different arms read as follows: $M = 1$ ohm, $N = 100$ ohms, and $P = 112$ ohms. Then, substituting these values in the fundamental equation gives

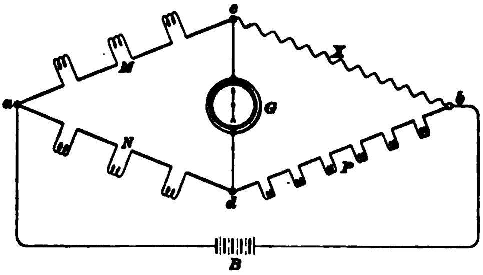


FIG. 41.

$$X = \frac{M}{N} \times P = \frac{1}{100} \times 112 = 1.12 \text{ ohms.}$$

54. The actual various forms of resistance boxes used with the bridges differ widely from the diagram, but all are based upon this same principle and fundamental equation. A common pattern of resistance box for this purpose is constructed similar to the adjustable rheostat, as previously described, where the adjustments are made with removable plugs. Ordinarily, the contact pieces are arranged in the shape of a letter S, and the galvanometer and battery circuits are connected as shown in Fig. 42. The position of the two balance arms and the adjustable arm can be readily seen by comparing the connections of the battery and galvanometer circuits with those in the original diagram. K and K' represent keys for opening the circuits when the plugs are withdrawn or inserted in varying the resistance or when the bridge is not in use. In this particular case, the 1,000-ohm plug in the upper balance arm is supposed to be drawn, and therefore $M = 1,000$ ohms. In the lower balance arm the 10-ohm plug is supposed to be drawn, and therefore $N = 10$ ohms. In the adjustable arm the following plugs are supposed to be drawn: 1, 2, 5, 10, 20, 100, 200, 500, 2,000, and 3,000 ohms; therefore, the resistance P is the sum of these resistances, or 5,838 ohms. If, under these conditions, there is no deflection of the galvanometer when the two keys K and K' are pressed and both circuits are closed, the resistance of X will be 583,800 ohms; for, substituting the values of M, N, and P in the fundamental equation gives $X = \frac{M}{N} \times P = \frac{1,000}{10} \times 5,838 = 583,800$ ohms.

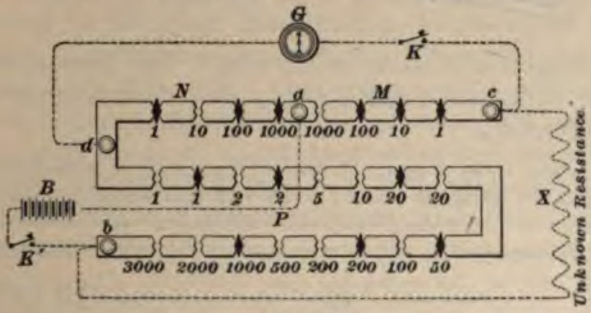


FIG. 42

Fig. 43 shows a special pattern of resistance box for a Wheatstone bridge, in which the coils of the adjustable arm

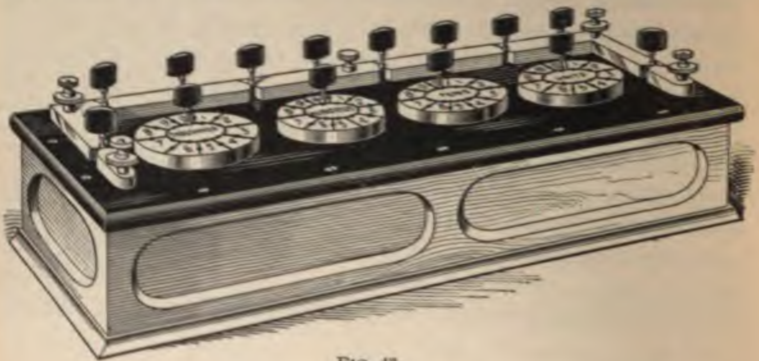


FIG. 43.

are arranged in the form of four dials. This pattern is known as the *dial* pattern, and is widely used in making resistance measurements.

EXAMPLE.—The diagram in Fig. 44 represents a particular type of Wheatstone's bridge to which a battery and galvanometer are properly connected for measuring unknown resistances. An unknown resistance x is connected to the terminals A and H; when the plugs a, e, f,

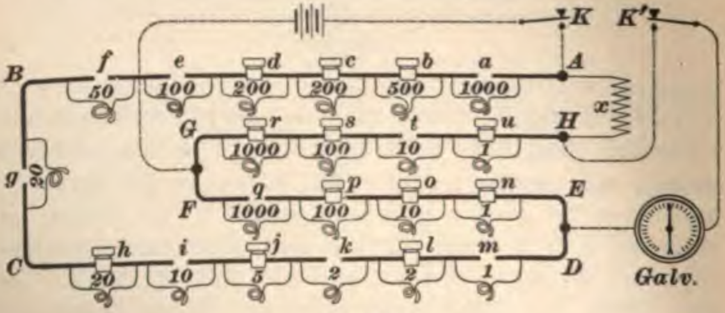


FIG. 44.

g, i, k, m, q, and t are drawn, and when both the contact keys K and K' are pressed, the galvanometer shows no deflection. Determine the resistance of x.

SOLUTION.—From the connections of the galvanometer and battery circuits, it will be seen that the resistance coils in line $G\,H$ represent the upper balance arm M of the bridge; that the coils in the line $E\,F$

represent the lower balance arm N; and that the coils in the lines $A\,B$ and $C\,D$ represent the adjustable arm P. From the fundamental equation of the Wheatstone bridge, X (the unknown resistance) $= \frac{M}{N} \times P$. In this particular case, the plug t in the upper arm is drawn; hence, $M = 10$ ohms; in the lower arm q is drawn; hence, $N = 1{,}000$ ohms; and in the adjustable arm, the plugs a, e, f, g, i, k, and m are drawn; hence, $P = 1{,}000 + 100 + 50 + 20 + 10 + 2 + 1 = 1{,}183$ ohms. Substituting these values in the fundamental equation gives $X = \frac{M}{N} \times P = \frac{10}{1{,}000} \times 1{,}183 = 11.83$ ohms. Ans.

55. The Volt, or the Practical Unit of Electromotive Force.—In mechanics, pressures of all kinds are measured by the *effects* they produce; similarly, in electrotechnics, *potential* is measured by the effect it produces.

It has been shown that electrical potential will cause an electric current to flow against the resistance of a conductor, and also how the units of resistance and current are obtained. It follows that a *unit potential* would be that electromotive force which would maintain a current of unit strength in a circuit whose resistance is unity. By definition, therefore, the *volt*, or *the practical unit of potential*, is that electromotive force which will maintain a current of *one ampere* in a circuit whose resistance is *one ohm*. With a known resistance in ohms and a known strength of current in amperes, the electromotive force in volts is determined by Ohm's law, Art. **34**, for, by transposing, $E = C\,R$.

This method of determining the potential of a circuit can be readily shown by the following illustration: Suppose, for example, it is desired to determine the electromotive force in volts required to drive a current of 2 amperes through a certain copper wire. In the first place, the resistance of the copper wire is found by Wheatstone's bridge as previously described. For convenience, it is assumed that its resistance is found to be 1.2 ohms. Then the electromotive force E required to drive 2 amperes through the wire will be 2.4 volts, for, by substituting, $E = C\,R = 2 \times 1.2 = 2.4$ volts.

The maximum difference of potential developed by any single voltaic couple placed in any electrolyte is about 2.25 volts; in the common forms of cells, the difference of potential developed averages from .75 to 1.75 volts.

56. When several cells are connected in *series*, the total electromotive force developed will be equal to the sum of the electromotive forces developed by the separate cells; or, if the cells are composed of the same voltaic elements, the total electromotive force developed will be equal to the electromotive force of one cell multiplied by the number of cells in series. For example, a battery is composed of 12 cells connected in series, and the electromotive force in each cell is 1.5 volts; the total electromotive force of the battery is, therefore, 1.5 × 12 = 18 volts.

Connecting cells in *parallel*, or *multiple-arc*, does not increase the electromotive force of a battery; the electromotive force will always be equal to the electromotive force of one cell, no matter how many cells are connected to the main conductors, provided, of course, that all cells develop equal electromotive forces.

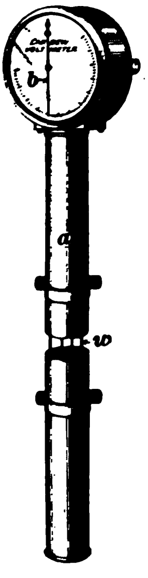


FIG. 45.

57. Measuring instruments called **voltmeters** have been devised for indicating electromotive forces and differences of potential directly in volts.

The **Cardew** voltmeter, Fig. 45, depends for its operation upon the linear expansion of a metallic wire when heated by an electric current. The expansion wire *w* is enclosed in a long cylindrical case *a*, and is attached in such a way that its expansion causes a small grooved wheel on the axis of the index needle to revolve in one direction when the wire expands, or lengthens, and in the opposite direction when the wire contracts, or shortens. The movements of this wheel cause the index *b* to move over the scale. Since the resistance is nearly constant, the current that will flow is proportional to the E. M. F.; the greater the E. M. F. the more the wire will be expanded, and the greater will be the consequent deflection. The resistance of the wire, however, is so large as to permit only a weak current to pass through it when the needle is deflected over the entire scale. A Cardew voltmeter which indicates up to 100 volts has a resistance of about 500 ohms. The circular scale is divided into small divisions, each representing one volt or fractions or multiples of one volt.

58. The **Weston voltmeter,** Fig. 46, is based upon the same principles as the Weston ammeter, and in appearance is quite similar to it. Its internal resistance, as in all voltmeters, is exceedingly large; the resistance of a Weston voltmeter for indicating up to 150 volts is about 19,000 ohms, while the resistance of a Weston ammeter, measuring strengths of currents up to 15 amperes, is only .0022 ohm. It will be seen that, owing to the great resistance, the current passing through a voltmeter is exceedingly small. For example, in the instrument described above, when indicating 150 volts, the current, by Ohm's law, is only 150 ÷ 19,000 = .0079 ampere. All voltmeters are provided with at least two terminals, or binding posts, such as p and p', Fig. 46. Connections are made by two separate conductors, called *voltmeter leads*, from these binding posts to two points between which the difference of potential, or the electromotive force, is to be measured.

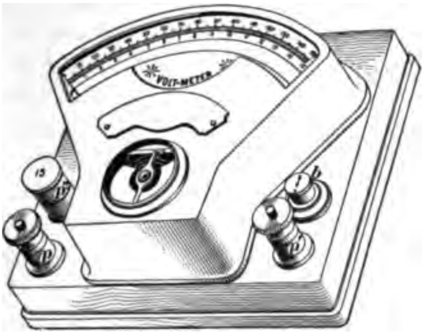


FIG. 46.

The Weston voltmeters usually have a third binding post p'', which when used with p' corresponds with a second graduated scale situated directly under the main scale, one division of the upper scale having the value of two lower divisions. The majority of voltmeters are also provided with a contact button *b*, which when pressed closes the circuit and allows the index needle to be deflected by the current. When the pressure upon the button is relaxed, the circuit is opened, and the index needle returns to the zero mark.

59. The methods of connecting voltmeters and ammeters for measuring electromotive forces and currents of various circuits should be thoroughly understood. Suppose, for example, that the terminals of a battery composed of four cells connected in series are connected to an unknown resistance, and it is desired to know the strength of current flowing through the circuit, and also the difference of potential required to drive that current through the unknown resistance when the only instruments available are an ammeter and a voltmeter. In Fig. 47 let *B* represent the battery and *R* the unknown resistance; *C*, *C'*, and *C''* are three large conductors for making necessary connections. With the connections shown, there is practically a continuous current flowing through the closed circuit, that is, from the battery through the conductors and the unknown resistance. The first step is to determine the strength of this current by the use of an ammeter. Assuming that the battery is constant, that is, that the electromotive force developed in it does not vary, then, so long as the resistance of the circuit is not altered, the strength of the current will remain unchanged and *will be the same in all parts of the circuit*. Hence, if an ammeter be inserted in any part of the

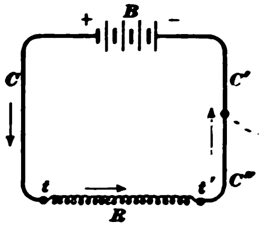


FIG. 47.

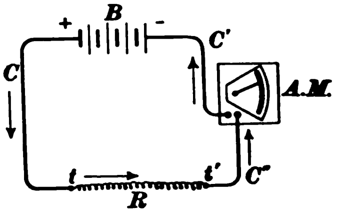


FIG. 48.

circuit, as between C' and C'', Fig. 48, it will measure the total strength of current flowing through the entire circuit. As has been stated, the internal resistance of the ammeter is so small that its insertion makes no appreciable change in the total resistance of the circuit, and therefore does not to any extent affect the current flowing. For convenience, assume that the strength of the current flowing in the circuit is found to be 1.2 amperes. The next operation is to find the electromotive force required to drive a current of 1.2 amperes through the resistance R; or, in other words, to find the difference of potential between the terminals t and t' when a current of 1.2 amperes is flowing in the circuit. This is accomplished by connecting the two terminals t and t', Fig. 49, of the unknown resistance R, to the two binding posts p and p' of the voltmeter $V\,M$ by two voltmeter leads l and l'. Any small wires of reasonable length can be used for voltmeter leads, as the current they transmit is exceedingly weak, owing to the extremely high resistance of the voltmeter. After pressing the contact button, assume the needle indicates a potential of 6 volts; this, then, is the electromotive force required to force a current of 1.2 amperes through the unknown resistance R; or, in other words, the difference of potential between the terminals t and t' is 6 volts. From these readings of the current and voltage, and by the application of Ohm's law, the resistance R of the circuit between t and t' can be determined. By algebra, Ohm's law can be transposed from the equation $C = \frac{E}{R}$ to $R = \frac{E}{C}$ and be equally true; this signifies that the resistance R of any conductor, or circuit, is equal to the electromotive force, or the difference of potential E in volts, divided by the strength of current C in amperes flowing through that

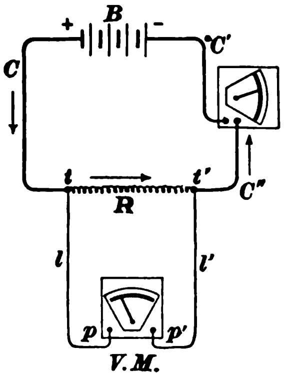


Fig. 49.

circuit or conductor. In the previous case, it has been found that it requires an electromotive force of 6 volts to drive a current of 1.2 amperes through the resistance R; hence, from Ohm's law, $R = \frac{E}{C} = \frac{6}{1.2} = 5$ ohms.

APPLICATIONS OF OHM'S LAW.

TO CLOSED CIRCUITS.

60. The following facts are to be carefully noted regarding the application of Ohm's law to closed circuits:

The strength of current (C) *is the same in all parts of a closed circuit, except in the cases of derived circuits, where the sum of the currents in the separate branches is always equal to the current in the main or undivided circuit.*

The resistance (R) *is the resistance of the internal circuit plus the resistance of the external circuit.*

The electromotive force (E) *in a closed circuit is the total generated difference of potential in that circuit.*

61. The following formula may be used to determine the strength of current in amperes flowing in a closed circuit when the electromotive force and the total resistance are known:

$$C = \frac{E}{R}, \qquad \textbf{(6.)}$$

where C = current in amperes;
E = electromotive force in volts;
R = resistance in ohms.

That is to say, *the strength of current in amperes is found by dividing the electromotive force in volts by the total resistance in ohms.*

EXAMPLE.—The two electrodes of a simple voltaic cell are connected by a conductor whose resistance is 1.6 ohms. If the internal resistance of the cell is 5 ohms and the total electromotive force developed is 5 volts, what is the strength of current flowing in the circuit?

SOLUTION.—Let r_i = the internal resistance and r_e = the resistance of the copper wire. Then, $R = r_i + r_e = 1.6 + 5 = 6.6$ ohms, the total resistance of the circuit. Then, by formula **6**, the current

$$C = \frac{E}{R} = \frac{1.75}{6.6} = .265 \text{ ampere. Ans.}$$

62. The following formula may be used to find the total resistance in ohms of a closed circuit when the electromotive force and the strength of current are known:

$$R = \frac{E}{C}, \qquad (7.)$$

the letters having the same significance as in formula **6.** By formula **7** it will be seen that *the resistance in ohms of a closed circuit is found by dividing the electromotive force in volts by the current in amperes.*

EXAMPLE.—The total electromotive force developed in a closed circuit is 1.8 volts and the strength of the current flowing is .6 ampere; find the resistance in ohms.

SOLUTION.—By formula **7**, the resistance

$$R = \frac{E}{C} = \frac{1.8}{.6} = 3 \text{ ohms. Ans.}$$

63. The following formula may be used to find the total electromotive force in volts developed in a closed circuit when the strength of current and the total resistance are known:

$$E = C R. \qquad (8.)$$

The letters have the same meaning as in formulas **6** and **7.** We find here that *the electromotive force in volts developed in a closed circuit is obtained by multiplying together the current in amperes and the resistance in ohms.*

EXAMPLE.—The internal resistance of a closed circuit is 2 ohms and the external resistance is 3 ohms; if the current flowing is .4 ampere, what is the electromotive force developed?

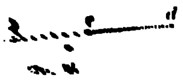
SOLUTION.—Let r_i = the internal resistance and r_e = the external resistance. Then, $R = r_i + r_e = 2 + 3 = 5$ ohms. By formula **8**, the electromotive force

$$E = C R = .4 \times 5 = 2.0 \text{ volts. Ans.}$$

TO DROP, OR LOSS, OF POTENTIAL.

64. Referring again to water flowing in a pipe, it is evident that although the *quantity* of water which passes is the same at any cross-section of the pipe, the *pressure per square inch* is not the same. Even in the case of a horizontal pipe of the same diameter throughout, the water when flowing suffers a *loss* of head, or pressure. It is this difference of pressure that causes the water to flow between two points against the friction of the pipe.

This is precisely similar to a current of electricity flowing through a conductor. Though the *quantity of electricity* that flows is equal at all cross-sections, the electromotive force is by no means the same at all points along the conductor. It suffers a loss, or drop, of electrical potential in the direction in which the current is flowing, and it is this difference of electrical potential that causes the electricity to flow against the resistance of the conductor. *Ohm's law* not only gives the strength of the current in a closed circuit, but also the *difference of potential* in volts along that circuit. The difference of potential (E) in volts between any two points along a circuit is equal to the product of the strength of the current (C) in amperes and the resistance (R) in ohms of that part of the circuit between those two points [illegible] R, which is an example of the use of formula 8, [illegible] also represents the loss, or *drop*, of potential in volts between the two points. If any two of these quantities are known, the third can be readily found; for, transposing, $C = \frac{E}{R}$ and $R = \frac{E}{C}$, as already given in formulas 6 and 7.



[illegible] Fig. [illegible] represents part of a circuit in which a current of 3 amperes is flowing. The resistance from [illegible] to [illegible] is 1.5 ohms, from [illegible] to [illegible] is 2.3 ohms, and from [illegible]. Find the difference of potential between a and b.

[illegible]

[illegible].—Since by formula 8, $E = C \times R$, then,

the difference of potential between a and $b = 3 \times 1.5 = 4.5$ volts.
" " " " " b and $c = 3 \times 2.3 = 6.9$ "
" " " " " c and $d = 3 \times 3.6 = 10.8$ "
" " " " " a and $d = 4.5 + 6.9 + 10.8 =$
22.2 volts; or, in other words, the *loss*, or *drop*, of potential caused by a current of 3 amperes flowing between a and d is 22.2 volts.

65. In a great many cases it is desirable to have the current flow from the source a long distance to some electrical receptive device and return without causing an excessive drop, or loss, of potential in the conductors leading to and from the two places. In such circuits, the greater part of the total generated electromotive force is expended in the receptive device itself, and only a small fraction of it is lost in the rest of the circuit. Under these conditions, it is customary to decide upon a certain *drop, or loss, of potential* beforehand, and from that and the current calculate the resistance of the two conductors.

EXAMPLE.—It is desired to transmit a current of 5 amperes to an electrical device situated 500 feet from the source; the total generated E. M. F. is 120 volts, and only $\frac{1}{10}$ of this potential is to be lost in the conductors leading to and from the receptive device. (*a*) Find the resistance of the two conductors, and (*b*) find the resistance per foot of the conductors, assuming each to be 500 feet long.

SOLUTION.—(*a*) $\frac{1}{10}$ of 120 volts = 12 volts, which represents the *drop*, or *loss*, of potential on the two conductors. Let $E' = 12$ volts; $C = 5$ amperes; and R' = the total resistance of the two conductors. Then, by formula **7**,

$$R' = \frac{E'}{C} = \frac{12}{5} = 2.4 \text{ ohms. Ans.}$$

(*b*) The resistance per foot of the conductor is found by formula **1**. In this case, $r_1 = 2.4$ ohms; $l_1 = 1{,}000$ feet; $l_2 = 1$ foot. Then the resistance per foot

$$r_2 = \frac{2.4 \times 1}{1{,}000} = .0024 \text{ ohm. Ans.}$$

TO VOLTAIC CELLS.

66. The difference of potential between the two electrodes of a simple voltaic cell when no current is flowing—that is, when the circuit is open—is always equal to the total electromotive force developed within the cell; but when a current is flowing—that is, when the circuit is *closed*—a certain amount of potential is expended in forcing the current through the internal resistance of the cell itself. Hence, the difference of potential between the two electrodes when the circuit is closed is always smaller than when the circuit is open. This difference of potential between the two electrodes when the circuit is closed is sometimes called the *available* or *external* eloctromotive force, to distinguish it from the *internal* or *total generated* electromotive force.

67. To find the available electromotive force of a cell,

let E = the total generated E. M. F.;
E' = *available* E. M. F. when the circuit is closed;
C = the current flowing when the circuit is closed;
r_i = the internal resistance of the cell.

Then, the drop, or loss, of potential in the cell = $C r_i$, and the available electromotive force

$$E' = E - C r_i. \qquad \textbf{(9.)}$$

The available electromotive force of a cell is equal to the difference between the total generated electromotive force and the potential expended in forcing the current through the internal resistance of the cell when the circuit is closed. From Ohm's law, this loss, or drop, of potential in the cell itself is equal to the product of the internal resistance in ohms and the strength of the current in amperes flowing through the circuit.

EXAMPLE.—In a voltaic cell, the total generated E. M. F. is 2.2 volts and the internal resistance is .8 ohm. If a current of 1.2 amperes flows through the cell when the circuit is closed, what is the available E. M. F., or, in other words, the difference of potential between the two electrodes?

SOLUTION.—Let E' = the available E. M. F.; E = the total generated electromotive force; C = the current in amperes; and r_i = the internal resistance.

Then, by formula **9**,

$$E' = E - C r_i = 2.2 - (1.2 \times .8) = 1.24 \text{ volts. } \textbf{Ans.}$$

TO DERIVED CIRCUITS.

68. In treating upon derived circuits, only that part of the circuit will be considered which is divided into branches and each branch transmitting part of the total current; the rest of the circuit is assumed to be closed through some electric source, as, for instance, a voltaic battery.

Before applying Ohm's law to derived circuits, the word *conductivity* should be thoroughly understood. Conductivity can be defined as the facility with which a body transmits electricity, and is the opposite of resistance. For example, copper is of low resistance and high conductivity; mercury is of high resistance and low conductivity. In other words, conductivity is the inverse or reciprocal of resistance. There is no established unit of conductivity; it is used merely as a convenience in calculations. For example, if the resistance of a circuit is 2 ohms, its conductivity is represented by one-half; if the resistance is increased to 4 ohms, the conductivity would only be one-half as much as in the former case and would be represented by one-quarter.

The **conductivity** of any conductor is, therefore, unity divided by the *resistance* of that conductor; and, conversely, the resistance of any conductor is unity divided by its conductivity.

69. Fig. 51 represents a derived circuit of two branches. Let r_1 and r_2 = the separate resistances of the two branches; c_1 and c_2 = the separate currents in each branch, respectively; and C = the sum of the currents in the two branches; that is, the current in the main or undivided branch. Then, $c_1 + c_2 = C$, and $C - c_2 = c_1$.

When the current flows from a to b, if the resistances r_1 and r_2 are equal, the current will divide equally between the two branches; thus, if a current of 2 amperes is flowing in the main circuit, 1 ampere will flow through each branch.

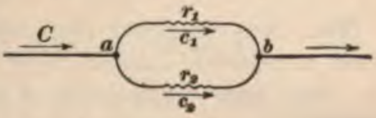


FIG. 51.

When the resistances of the two branches are unequal, the current will divide between them in inverse proportion to their respective resistances. In Fig. 51 the resistances of the two branches are r_1 and r_2. Therefore, $c_1 : c_2 :: r_2 : r_1$.

By algebra, this proportion gives the two following formulas:

For the first branch, $c_1 = \frac{C r_2}{r_1 + r_2}$. **(10.)**

That is, *of two branches in parallel, dividing from a main circuit, the current in the first branch is equal to the current in the main multiplied by the resistance of the second branch, and the product divided by the sum of the resistances of the two branches.*

For the second branch, $c_2 = \frac{C r_1}{r_1 + r_2}$. **(11.)**

Of two branches in parallel, dividing from a main circuit, the current in the second branch is equal to the current in the main multiplied by the resistance of the first branch, and the product divided by the sum of the resistances of the two branches.

EXAMPLE.—Suppose the resistance r_1 of the first branch is 2 ohms, and the resistance r_2 of the second branch is 3 ohms, find the separate currents c_1 and c_2 in the two branches, respectively, when the current C in the main or undivided branch is 60 amperes.

SOLUTION.— $r_1 = 2$ ohms, $r_2 = 3$ ohms, and $C = 60$ amperes. To find the current c_1 in the first branch, substitute these values in formula **10,** which will give

$$c_1 = \frac{C r_2}{r_1 + r_2} = \frac{60 \times 3}{2 + 3} = \frac{180}{5} = 36 \text{ amperes. Ans.}$$

To find the current c_2 in the second branch, substitute these values in formula **11,** which will give

$$c_2 = \frac{C r_1}{r_1 + r_2} = \frac{60 \times 2}{2 + 3} = \frac{120}{5} = 24 \text{ amperes. Ans,}$$

70. It is clear that two conductors in parallel will conduct an electric current more readily than one alone; that is, their *joint conductivity* is greater than either of their separate conductivities taken alone. [illegible]g the case their resistances must follow the inverse law—viz., the joint resistance of two conductors in parallel must be *less* than either of their separate resistances taken alone.

Rule.—*If the separate resistances of two conductors are equal, their joint resistance when connected in parallel is one-half of the resistance of either conductor.*

For example, take two conductors, the separate resistance of each being 2 ohms, and connect them in parallel; their joint resistance will then be one-half their separate resistance, or 1 ohm.

71. When the separate resistances of two conductors in parallel are unequal, the determination of their joint resistance when connected in parallel involves some calculation.

In Fig. 51, the conductivities of the branches are $\frac{1}{r_1}$ and $\frac{1}{r_2}$. Hence, their joint conductivity when connected in parallel is $\frac{1}{r_1} + \frac{1}{r_2} = \frac{r_2 + r_1}{r_1 r_2}$; now, since the resistance of any conductor is the reciprocal of its conductivity, then the *joint resistance* of the two branches in parallel is the reciprocal of their joint conductivity; or, $1 \div \frac{r_2 + r_1}{r_1 r_2} = \frac{r_1 r_2}{r_2 + r_1}$. Hence, joint resistance

$$R' = \frac{r_1 r_2}{r_1 + r_2}. \qquad \textbf{(12.)}$$

That is, *the joint resistance of two conductors connected in parallel is equal to the product of their separate resistances divided by the sum of their separate resistances.*

Example.—In Fig. 51, given $r_1 = 2$ ohms and $r_2 = 3$ ohms; find their joint resistance in parallel.

Solution.—From formula **12**, their joint resistance

$$R' = \frac{r_1 r_2}{r_1 + r_2} = \frac{2 \times 3}{2 + 3} = \frac{6}{5} = 1\tfrac{1}{5} \text{ ohms. Ans.}$$

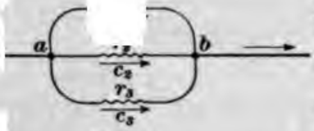


FIG. 52.

.epresents a divided circuit of three branches. Let r_1, r_2, and r_3 be the separate resistances of those branches, respectively. Then, $\frac{1}{r_1}$, $\frac{1}{r_2}$, and $\frac{1}{r_3}$ represent the separate con- he three branches, respectively. Their joint

$$= \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} = \frac{r_2 r_3 + r_1 r_3 + r_1 r_2}{r_1 r_2 r_3}.$$

Since the esistance is the reciprocal of their joint conductivity, it is equal to

$$1 \div \frac{r_2 r_3 + r_1 r_3 + r_1 r_2}{r_1 r_2 r_3} = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}.$$

nce, the joint resistance of three branches in parallel

$$R''' = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}. \qquad \textbf{(13.)}$$

'hat is, *the joint resistance of three or more conductors nected in parallel is equal to the reciprocal of their joint onductivity.*

EXAMPLE.—In Fig. 52, given $r_1 = 5$ ohms; $r_2 = 10$ ohms; and $r_3 = 20$ ohms; find their joint resistance from a to b.

SOLUTION.—By formula **13**, their joint resistance

$$R''' = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2} = \frac{5 \times 10 \times 20}{10 \times 20 + 5 \times 20 + 5 \times 10} = \frac{1,000}{350} = \frac{20}{7}$$

$= 2\frac{6}{7}$ ohms. Ans.

73. In a derived circuit of any number of branches, the difference of potential between where the branches divide and where they unite is equal to the product of the sum of the currents in the separate branches and their joint resistance in parallel, as will be apparent from consideration of Ohm's law, Art. **34.**

For example, if the currents in the three branches, Fig. 52, are 16, 8, and 4 amperes, respectively, and the joint resistance from a to b is $2\frac{6}{7}$ ohms, then the difference of potential between a and $b = (16 + 8 + 4) \times 2\frac{6}{7} = 28 \times \frac{20}{7} = 80$ volts.

74. The separate currents in the branches of a derived circuit can be determined by finding the difference of potential between where the branches divide and where they unite, and dividing the result by the separate resistance of each branch.

For example, in Fig. 52, assume that the separate resistances of the three branches are 5, 10, and 20 ohms, respectively, and that the difference of potential between a and b is 80 volts. Then, the current in the first branch is $\frac{80}{5} = 16$ amperes; in the second, $\frac{80}{10} = 8$ amperes; and in the third, $\frac{80}{20} = 4$ amperes.

75. The separate resistances of the branches of a derived circuit can be determined by finding the difference of potential between where the branches divide and where they unite, and dividing the result by the separate currents in each branch.

For example, in Fig. 52, assume the difference of potential between a and b to be 80 volts and the currents in the separate branches to be 16, 8, and 4 amperes, respectively; then, the resistance of the first branch is $\frac{80}{16} = 5$ ohms; of the second, $\frac{80}{8} = 10$ ohms; and of the third, $\frac{80}{4} = 20$ ohms.

Example.—Fig. 53 represents a closed circuit, part of which, from a to b, forms a derived, or shunt, circuit of three separate branches A, B, and C in parallel; r_1, r_2, and r_3 represent the separate resistance of the branches, respectively, from a to b; and R' represents the resistance of the rest of the closed circuit from b to a in the direction in which the current is supposed to be flowing, including the internal resistance of the battery K. Let $r_1 = 2$ ohms; $r_2 = 3.2$ ohms; $r_3 = 4.4$ ohms; and $R' = .8$ ohm. If a current of 2 amperes is flowing in the main, or undivided, circuit, find the total electromotive force developed in the battery K.

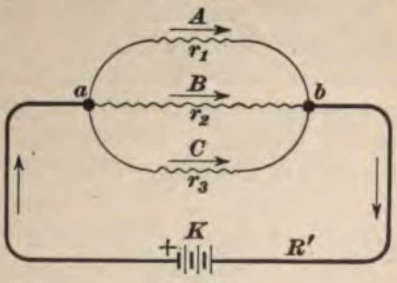


FIG. 53.

Solution.—From the application of Ohm's law to closed circuits, formula **8**, $E = C R$, where E is the total electromotive force developed within the electric source; C the strength of current flowing; and

R the total resistance of the circuit through which the current passes. In this particular problem, the total resistance of the closed circuit will be the *joint* resistance of the three branches in parallel, plus the resistance R' of the rest of the circuit. Hence, first find the joint resistance of the three branches A, B, and C in parallel from a to b. By formula **13**, the joint resistance of three conductors in parallel is $\frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}$, where r_1, r_2, and r_3 represent the separate resistances of the three conductors. Substituting gives

$$\frac{2 \times 3.2 \times 4.4}{3.2 \times 4.4 + 2 \times 4.4 + 2 \times 3.2} = \frac{28.16}{14.08 + 8.8 + 6.4} = \frac{28.16}{29.28} = .9617 \text{ ohm},$$

the joint resistance of the three branches A, B, and C in parallel from a to b. The total resistance of the closed circuit is, therefore, $.9617 + .8 = 1.7617$ ohms, and $E = C \times R = 2 \times 1.7617 = 3.5234$ volts. Ans.

ELECTRICAL QUANTITY.

76. The rate of flow of liquids is expressed in units of quantity per second or minute, and similarly the strength of an electric current can be defined as a quantity of electricity flowing per second. The practical unit of *electrical quantity* is called the **coulomb**.

The coulomb is such a quantity of electricity as will pass in one second through a circuit in which the strength of current is one ampere.

As stated previously, the *quantity* of electricity is calculated from the strength of current; it cannot be actually measured. For example, suppose the strength of current in a closed circuit to be 10 amperes, as measured by an ammeter; if such a current flows for only one second, the quantity of electricity which has passed around the circuit is 10 coulombs; but if the current flows for two seconds, the quantity of electricity would be 20 coulombs.

Hence, to calculate the quantity of electricity which has passed in a circuit in a certain time when the strength of the current in amperes is known:

Let $Q =$ the quantity of electricity in coulombs, C the strength of current in amperes, and t the time in seconds.

Then, $$Q = C t. \qquad \textbf{(14.)}$$

If any two of these quantities are known, the third can be readily found. By transposition, $C = \frac{Q}{t}$ and $t = \frac{Q}{C}$.

Therefore, to obtain the quantity of current which has passed through a circuit in a given time, *multiply the strength of current in amperes by the time in seconds.*

EXAMPLE.—Find the quantity of electricity in coulombs that flows around in a closed circuit in 1½ hours when the strength of current is 12 amperes.

SOLUTION.—Reducing the time to seconds gives $1.5 \times 60 \times 60 = 5{,}400$ seconds; hence, $t = 5{,}400$ seconds and $C = 12$ amperes. Then from formula **14**,

$$Q = C\,t = 12 \times 5{,}400 = 64{,}800 \text{ coulombs. Ans.}$$

ELECTRICAL WORK.

77. When an electric current flows from a higher to a lower potential, *electrical energy* is expended and *work* is done by the current. The principle of the *conservation of energy* teaches that energy can never be destroyed; it follows, therefore, that if energy has to be expended in forcing a quantity of electricity against a certain amount of resistance, the equivalent of that energy must be transformed into some other form. This other form is usually *heat;* that is, when a quantity of electricity flows against the resistance of a conductor, a certain amount of *electrical* energy is transformed into *heat* energy.

The actual amount of heat developed is an exact equivalent of the *work done* in overcoming the resistance of the conductor, and varies directly as that resistance. For example, take two wires, the resistance of one being twice that of the other, and send currents of equal strengths through each. The amount of heat developed in the wire of higher resistance will be twice that developed in the wire offering the lower resistance.

The unit used to express the amount of mechanical work done is known as the *foot-pound.* The work done in raising any mass through any height is found by multiplying the weight of the body lifted by the vertical height through which it is raised; similarly, the practical unit of *electrical work* is that amount accomplished when a unit quantity of electricity, *one coulomb*, flows between potentials differing by *one volt*.

The unit of electrical work is, therefore, the *volt-coulomb*, and is called the **Joule.**

1 *joule* = .7373 foot-pound.

78. By means of the following formulas, we may find directly the amount of electrical work accomplished in *joules* during a given time in any circuit:

Let J = electrical work in joules;
C = current in amperes;
t = time in seconds during which the current flows;
E = potential, or E. M. F., of circuit;
R = resistance of circuit.

When the current and electromotive force are known,

$$J = C E t. \qquad \textbf{(15.)}$$

When the current and resistance are known,

$$J = C^2 R t. \qquad \textbf{(16.)}$$

When the resistance and electromotive force are known,

$$J = \frac{E^2 t}{R}. \qquad \textbf{(17.)}$$

To determine, therefore, the electrical work done in a given time, *multiply the quantity of electricity in coulombs which has passed in the circuit during that time by the loss, or drop, of potential as measured directly, or as computed from the values of the current and resistance.*

EXAMPLE.—Find the amount of work done in joules when a current of 15 amperes flows for ½ an hour against a resistance of 2 ohms.

SOLUTION.—Reducing the time to seconds gives 30 × 60 = 1,800 sec.; the current = C = 15 amperes, and the resistance = 2 ohms. By formula **16**, the electrical work done

$J = 15^2 \times 2 \times 1,800 = 810,000$ joules. Ans.

79. When the work in joules is known, the work in foot-pounds

$$\text{F. P.} = .7373\,J. \qquad \textbf{(18.)}$$

That is, *the equivalent work done in foot-pounds is obtained by multiplying the number of joules by .7373.*

Example.—Express the work done in foot-pounds in a circuit when a current of 8 amperes flows for 2 hours between potentials differing by 10 volts.

Solution.—Reducing the time to seconds gives $2 \times 60 \times 60 = 7{,}200$ seconds $= t$. The current $= 8$ amperes $= C$, and the electromotive force $= 10$ volts $= E$. Then, by formula **15**, the electrical work done $= J = 8 \times 10 \times 7{,}200 = 576{,}000$ joules. Expressed in foot-pounds, this will be, by formula **18**,

$$\text{F. P.} = .7373 \times 576{,}000 = 424{,}684.8 \text{ foot-pounds. Ans.}$$

ELECTRICAL POWER.

80. Power, or *rate of doing work*, is found by dividing the amount of work done by the time required to do it. In mechanics, the unit of power is called the **horsepower**; in electrotechnics, the unit of power is the **watt.** It is found by dividing the amount of electrical work done by the time required to do it.

Let $E =$ the electromotive force in volts; Q, the quantity of electricity in coulombs; C, the current in amperes; and W, the power in watts.

By formula **15,** the amount of electrical work $J = C E t$.

Then, $$W = \frac{C E t}{t} = C E. \qquad \textbf{(19.)}$$

The power in watts is equal to the strength of current in amperes multiplied by the electromotive force in volts.

Example.—What is the power in watts developed in a closed circuit in which a current of 12 amperes is flowing between potentials differing by 25 volts?

Solution.— $E = 25$ volts and $C = 12$ amperes. Hence, by formula **19,**

$$W = C E = 12 \times 25 = 300 \text{ watts. Ans.}$$

By taking into consideration the resistance of the circuit, the equation for determining the power in watts may be expressed in two other ways:

By derivation from formula **16**,

$$W = \frac{C^2 R t}{t} = C^2 R. \qquad (20.)$$

hat is, *the power in watts is equal to the strength of cur- in amperes squared, multiplied by the resistance in ohms.*

XAMPLE.—Find the power in watts in a closed circuit in which a rrent of 30 amperes is flowing against a resistance of 3 ohms.

SOLUTION.— $C = 30$ and $R = 3$. Hence, by formula **20**,

$$W = C^2 R = 30^2 \times 3 = 2{,}700 \text{ watts. Ans.}$$

By derivation from formula **17**,

$$W = \frac{E^2 t}{R t} = \frac{E^2}{R}. \qquad (21.)$$

That is, *the power in watts is the quotient arising from dividing the electromotive force in volts squared by the resistance in ohms.*

EXAMPLE.—The drop of potential in a closed circuit when a current is flowing is 20 volts and the resistance is 10 ohms; what is the power in watts expended?

SOLUTION.— $E = 20$ volts and $R = 10$ ohms. Hence, by formula **21**,

$$W = \frac{E^2}{R} = \frac{20^2}{10} = 40 \text{ watts. Ans.}$$

81. One watt equals $\frac{1}{746}$ of a horsepower; or, 1 horsepower equals 746 watts.

If H. P. = horsepower,

$$\text{H. P.} = \frac{W}{746}. \qquad (22.)$$

That is, *to express the rate of doing electrical work in horsepower units, find the number of watts and divide the result by 746.*

The horsepower may also be expressed by three other equations, by expressing the watts in terms of electromotive force, current, and resistance, as obtained from formulas **19, 20, 21,** viz.:

$$\text{H. P.} = \frac{E\,C}{746};\ \text{H. P.} = \frac{C^2 R}{746};\ \text{and H. P.} = \frac{E^2}{746\,R}.$$

Example.—Given, current = 50 amperes and electromotive force = 250 volts; express the power directly in horsepower units.

Solution.— $E = 250$ volts; $C = 50$ amperes; hence,

$$\text{H. P.} = \frac{E\,C}{746} = \frac{250 \times 50}{746} = 16.756 \text{ horsepower. Ans.}$$

Example.—Given, strength of current = 25 amperes and resistance = 14.92 ohms; express the power directly in horsepower units.

Solution.— $C = 25$ amperes; $R = 14.92$ ohms; hence,

$$\text{H. P.} = \frac{C^2 R}{746} = \frac{25^2 \times 14.92}{746} = 12.5 \text{ horsepower. Ans.}$$

Example.—Given, electromotive force = 110 volts and resistance = 4 ohms; express the power directly in horsepower units.

Solution.— $E = 110$ volts; $R = 4$ ohms; hence,

$$\text{H. P.} = \frac{E^2}{746\,R} = \frac{110^2}{746 \times 4} = 4.055 \text{ horsepower. Ans.}$$

82. To express the power in watts when the horsepower is known, use the following formula:

$$W = \text{H. P.} \times 746. \qquad \textbf{(23.)}$$

That is to say, *the power in watts is found by multiplying the horsepower by 746.*

Example.—Express the equivalent of 4.35 horsepower in watts.

Solution.— H. P. = 4.35; by formula **23,** the electrical power $W = 4.35 \times 746 = 3{,}245.1$ watts. Ans.

83. The watt is too small a unit for convenient use in expressing the output of large dynamos, so the **kilowatt** is generally used. One kilowatt is equal to 1,000 watts or about 1⅓ horsepower. For example, if a dynamo were rated at 75 kilowatts, it would have an output of 75,000 watts or

ly about 100 horsepower. The **kilowatt-hour** is a
t of *work* commonly used in electrical work. It is the
amount of *work* done when 1 kilowatt is expended for
1 hour, or ½ kilowatt for 2 hours, etc. The kilowatt-hours
e, therefore, found by multiplying the average number of
owatts by the average number of hours during which the
owatts were expended. Since 1 kilowatt = 1,000 watts,
ilowatt-hour = 1,000 watt-hours. Now 1 watt expended
1 second is equal to 1 joule; hence, 1 kilowatt-hour
1,000 × 3,600 = 3,600,000 joules, or 3,600,000 × .7373
= 2,654,280 foot-pounds. The kilowatt-hour represents a
definite amount of work, whereas the kilowatt expresses the
te at which work is done, and is, therefore, a unit of power.

DYNAMOS AND MOTORS.

ELECTROMAGNETIC INDUCTION.

1. It has been shown that an electric current circulating around a coiled conductor produces lines of force which thread through the coil, entering at one end and leaving at the other. So long as the current in the coil remains at a constant strength, the lines of force have direction and position only; unless influenced by some exterior magnetic substance, they do not increase or diminish in number, or change their position relatively to the coil. Fig. 1 repre-

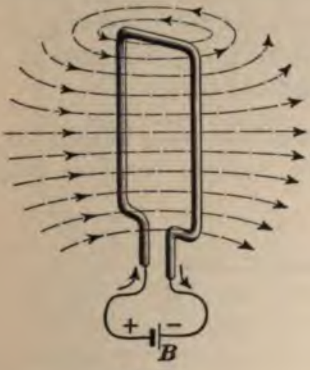


FIG. 1.

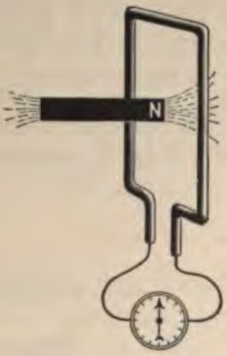


FIG. 2.

NOTE.—This section is the same as that formerly entitled *Dynamos and Motors*, Part 2.

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sents such a coil around which a current is flowing from the battery *B*. Suppose the battery is disconnected from the coil and a galvanometer for detecting small currents is inserted in its place. A magnetic pole suddenly thrown into the coil, as represented in Fig. 2, will cause a deflection of the galvanometer needle; the needle, however, will return to its original position as soon as the magnet comes to rest. Withdrawing the magnet from the coil also causes a deflection of the needle, but in the opposite direction. In the first case, a momentary current is induced in the circuit, as shown by the deflection of the galvanometer needle while the magnet is being inserted into the coil; this current immediately subsides when the magnet ceases to move. In the second case, the same effects are produced, with the exception that the current induced in the coil flows in an opposite direction to that in the first case.

These induced currents are caused by a change in the number of lines of force which pass through the coil. In passing into or out of the coil, the lines of force from the magnet set up an E. M. F. in that portion of the conductor in which the number of lines of force is changing, and this E. M. F. tends to send a current through the circuit.

2. In place of a small magnetic pole, imagine the coil to be suddenly inserted into a large uniform magnetic field where all the lines of force are parallel to one another. The diagram, Fig. 3, represents a cross-sectional view of such a field. The dots represent the ends of the lines of

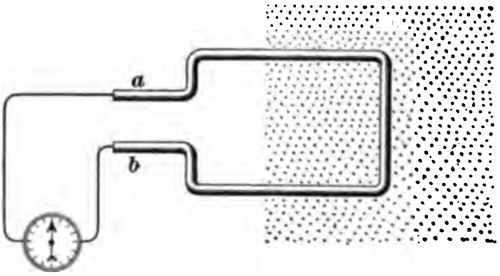


FIG. 3.

force; their direction is assumed to be downwards, piercing the paper, or, in other words, the observer is looking along the lines of force toward the face of a south magnetic pole. As the coil enters the magnetic field with its plane at right angles to the lines of force, a current will be induced in the coil and the galvanometer needle will be deflected; this induced current is produced by a change in the number of lines of force which pass through the coil, as in the previous case. Withdrawing the coil from the magnetic field will also induce a current in the circuit, but it will deflect the galvanometer needle in an opposite direction, showing that the current in the circuit is reversed.

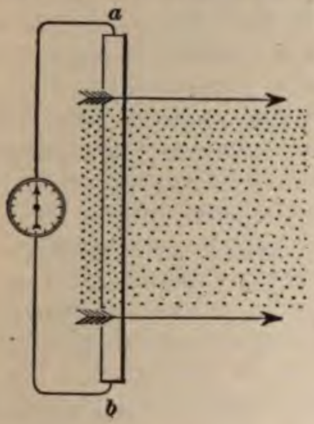


FIG. 4.

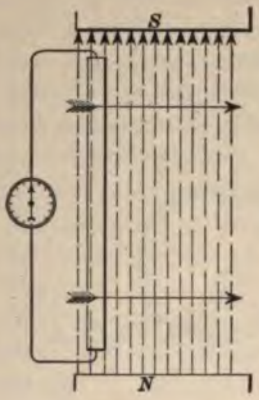


FIG. 5.

If the coiled conductor be straightened out, forming one long conductor, and then moved across the magnetic field at right angles to the lines of force, as represented in Fig. 4, a current will be generated in the circuit. The current, however, immediately subsides when the motion ceases, no matter whether the conductor is in the magnetic field or otherwise. Should the conductor be moved in the magnetic field, with its length parallel to the lines of force, as in Fig. 5, no current will be generated in the circuit. From these two experiments the following principle is deduced: *When a conductor is moved across a magnetic field so that* *it cuts the lines of force, an E. M. F. is generated which tends to send a current through that conductor.*

3. In reality, currents generated in a conductor *cutting* lines of force and those *induced* in a coiled conductor by a change in the number of lines of force which pass through the coil are due to the same movement; for, every conductor conveying an electric current forms a closed coil, and every line of force is a complete magnetic circuit by itself. Consequently, when any part of a closed coil is cutting lines of force, the lines of force are passing through the coil in a definite direction and changing at the same rate as the cutting. For example, in Fig. 6 the heavy loop *C. C.* represents a closed coil, and the light loop *L. F.* represents four lines of force. When the two closed loops are brought together, the closed coil is cut at one place *a* by four lines of force, and at the same time the number of lines of force passing through the closed coil increases from nothing to four. In calculations, however, it is convenient to make a distinction between the two cases: in the one case, to consider that the current is *generated* by a conductor of a certain length *cutting* lines of force at right angles; and in the other, to consider that the current in a closed coil is *induced* by a *change* in the number of lines of force passing through the coil.

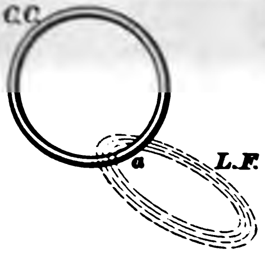


FIG. 6.

In these explanations, it must not be forgotten that an electric current is the result of a difference of potential or electromotive force. Consequently, it is not actually a current that is generated in the moving wire, but an electromotive force; for, in all of the previous experiments in which currents are induced or generated in a conductor by the lines of force, if the circuit is opened at any point, no current will flow, but the electromotive force still exists.

4. There are three methods of producing an electromotive force by induction in a coiled conductor; namely, by *electromagnetic induction*, by *self-induction*, and by *mutual induction.*

In **electromagnetic induction,** the change in the number of lines of force which pass through the coil is due to some relative movement between the coil and a magnetic field; as, for example, by thrusting a magnet into the coil or withdrawing it, or, again, by suddenly inserting the coil into a magnetic field with its plane at right angles to the lines of force.

5. In **self-induction,** the change in the number of lines of force is caused by sudden changes in a current which is already flowing through the coil itself and is supplied from some exterior source. This exterior current produces a magnetic field in the coil, and so long as the strength of the current remains constant, there is no change in the number of lines of force which pass through the coil. But if the strength of the current is suddenly increased, a change in the number of lines of force occurs; the change in turn *induces* an electromotive force in the conductor, which *opposes* the original current in the coil and tends to keep the current from rising. Its action is similar to that which would take place if some extra resistance were suddenly inserted into the circuit at the instant the strength of the current is increased. The original current eventually reaches its maximum strength in the coil as determined by Ohm's law, but its rise is not instantaneous; it is retarded to a certain extent by this induced electromotive force. If, on the contrary, the strength of the original current is suddenly allowed to decrease, another change is produced in the lines of force which pass through the coil; this new change induces an electromotive force in the coil which acts in the *same* direction as that of the original current and tends to keep it from falling. As in the previous case, however, the original current will eventually drop to its minimum strength, as determined by Ohm's law, but it will fall gradually, and a fraction of a second will elapse before it becomes constant. In short, the current flowing through a coiled conductor acts as if possessing *inertia;* any sudden change in the strength of the current produces a corresponding electromotive force which opposes that change and tends to keep the current at a constant strength.

6. In **mutual induction,** two separate coiled conductors, one conveying a current of electricity, are placed near each other, so that the magnetic circuit produced by the one in which the current flows is enclosed by the other, as shown in Fig. 7, where the current circulates around the coil *P* when the circuit is closed at key *b*. The coil *P* is called the **primary, or exciting, coil;** the other coil *S* is the **secondary coil.**

Any sudden change in the strength of the current circulating around the primary coil, as, for instance, breaking the circuit at *b*, produces a corresponding change in the number of lines of force in the magnetic circuit which passes through both coils, and hence an electromotive force is induced in the secondary coil. If the primary circuit is completed at *b* and the current tends to rise in that coil, the electromotive force induced in the secondary coil causes a current to circulate around in it in the *opposite* direction to the current in the primary coil. If, on the contrary, the circuit at *b* is suddenly opened and the current in the primary decreases, the induced electromotive force in the secondary causes a current to circulate around in it in the *same* direction as the current in the primary coil.

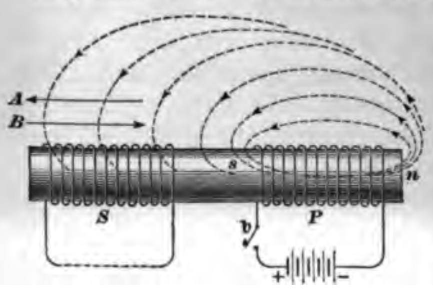


FIG. 7.

To make this clear, suppose, in Fig. 7, the current in the primary coil to be suddenly established by closing the switch at *b*. The lines of force will surround the conductors and spread out in all directions. The lines of force spreading out in the direction of arrow A cut the conductors of the secondary coil. The resulting current in the secondary would have the same direction were the lines of force stationary, as shown, and the coil S moved along the core in the direction of arrow B. Then, according to the thumb-and-finger rule, the current will flow in the secondary coil in a direction opposite to that in the primary. Similar reasoning will show that when the primary circuit is broken and the lines of force collapse, the direction of the current in the secondary coil S will be the *same* as that which existed in the primary.

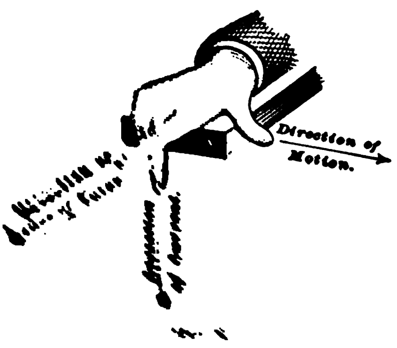
7. The direction of an induced current in a coil depends upon the direction of the lines of force in the coil and whether their number is increasing or diminishing. If these two facts are known, the direction in which the current circulates around the coil is determined by the following rule:

Rule.—*If the effect of the action is to diminish the number of lines of force that pass through the coil, the current will circulate around the coil in the direction of the movement of the hands of a watch as viewed by a person looking along the magnetic field in the direction of the lines of force; but if the effect is to increase the number of lines of force that pass through the coil, the current will circulate around in the opposite direction.*

For example, in the diagram, Fig. 3, when the coil is inserted into the magnetic field, thereby *increasing* the number of lines of force which pass through the coil, the current circulates from b around the coil to a, and thence through the galvanometer to b again; when the coil is withdrawn and the number of lines *diminishes*, the current circulates in the opposite direction, that is, from a around the coil to b, and thence through the galvanometer to a again. That end of the coiled conductor *from* which the current flows *to* the external circuit, as from a through the galvanometer, in the first case, is the *positive* pole or terminal of the coil; in the second case, *b* is the *positive* pole or terminal.

8. Referring to the straight conductor in which a current is generated by moving it across a magnetic field at right angles to the lines of force, the direction of the current in the conductor depends upon the relation of the direction of the lines of force to that of the moving conductor. The conductor must necessarily be moved across the magnetic field at some angle to the lines of force, and the current generated in the conductor will tend to flow at right angles to the lines of force and at right angles to the direction in which the conductor is moving. In Fig. 4, if the conductor is moved from left to right across the lines of force, the current generated in it will tend to flow upwards through the conductor; that is, from *b* to *a* through the conductor, then from *a* to *b* through the galvanometer. If the conductor is moved in the opposite direction, that is, from right to left, the current in the conductor will tend to flow in a reversed direction, that is, from *a* to *b* through the conductor and from *b* to *a* through the galvanometer. A convenient method for remembering the direction of a current generated in a straight conductor, when the conductor is moved in a magnetic field at right angles to the lines of force, is as follows:

Rule.—*Place thumb, forefinger, and middle finger of the right hand so that each will be perpendicular to the other two; if the forefinger points in the direction of the lines of force and the thumb points in the direction toward which the conductor is moving, then the middle finger will point in the direction toward which the current generated in the conductor tends to flow.*


Direction of Motion.

For example, in Fig. 8, if a vertical conductor be moved across the front of the north pole N of the magnet in the direction toward which the thumb points, the current generated in the conductor will flow downwards, that is, in the direction toward which the middle finger is pointing.

The summary of these electromagnetic induction experiments can be stated as follows: *Electromotive forces are generated in a conductor moving in a magnetic field at right angles to the direction of the lines of force, or are induced in a coiled conductor when a change occurs in the number of lines of force which pass through the coil.*

PHYSICAL THEORY OF THE DYNAMO.

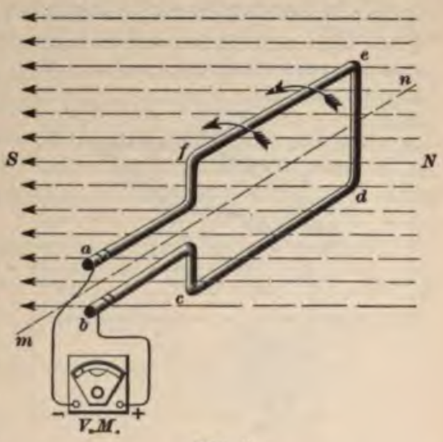


FIG. 9.

9. In Fig. 9, a rectangular coil of copper wire is placed in the center of a uniform field with its plane lying perpendicular to the lines of force; in this position, the coil encloses the greatest number of lines of force. A voltmeter $V\ M$ for measuring small E. M. F.'s is connected to the two ends of the coil, as shown in the diagram. The circuit in the voltmeter is kept closed, and any E. M. F. generated in the conductor will be indicated by the deflection of the index needle. So long as the coil remains at rest in the magnetic field no E. M. F. is generated; but imagine the coil to be rotated on an axis in its own plane, such as represented by the broken line $m\ n$, in the direction indicated by the curved again. The E. M. F. that is being generated at every instant during one-half of a revolution can be shown by a continuation of the curve on cross-section paper, Fig. 12. The sum of the divisions between *A* and *C* represents the total time occupied by the coil in rotating one-half of a revolution. It will be seen that the maximum E. M. F. that is being generated at any instant is at position *2*, Fig. 10, which corresponds to *B*, Fig. 12. In this position the plane of the coil lies parallel to the lines of force, and its sides, corresponding to *c d* and *e f*, Fig. 9, are cutting the lines of force at exactly right angles. The sides of the coil at the moment of passing through this position are cutting more lines of force for equal intervals of time than in any other position during the first half of a revolution.

From this fact the following principle is deduced: *The E. M. F. generated in a moving conductor cutting lines of force at right angles is directly proportional to the rate of cutting.* Suppose, for example, that a magnetic field contains 100,000 lines of force, and that a conductor is moved across the field at right angles in such manner as to cut every line of force. If the time occupied by the conductor in passing across the field is one second, then the rate of cutting is 100,000 lines per second; or, if it occupied two seconds, the rate of cutting is 50,000 lines per second, and so on. The E. M. F. generated in the former case is twice as great as that generated in the latter. The method for determining the number of lines of force in a magnetic field will be described later.

12. Fig. 13 shows the coil after being rotated one-half of a revolution. As soon as the coil starts on the last half of the revolution, its sides *c d* and *e f* cut a few lines of force, and, consequently, an E. M. F. is generated in each side. The E. M. F., however, tends to cause a current to flow in the coil in an opposite direction to that which tends to flow during the first half of the revolution. For, by applying the thumb-and-finger rule, the E. M. F. generated in the sides tends to cause a current to flow from *c* to *d* and from *e* to *f*; the end *a* of the coil, which in the first half of the revolution was the negative terminal of the coil, now forms the positive terminal. Hence, in order to allow the current to enter the positive binding post of the voltmeter, the connections must be reversed.

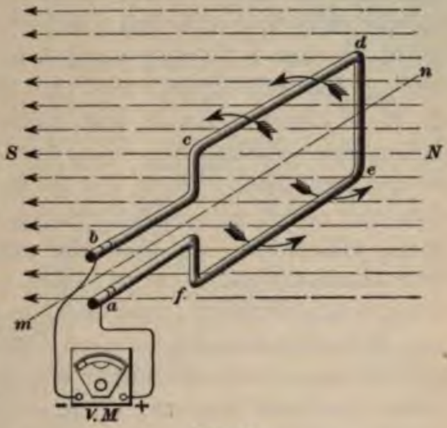


FIG. 13.

The E. M. F. that is generated as the coil is rotated through the last half of the revolution gradually rises as in the first half, reaching a maximum height when the plane of the coil lies parallel to the lines of force, and afterwards falling to zero again as the coil reaches a vertical position. In Fig. 14, the E. M. F. that is generated in the coil at every instant during one complete revolution is graphically shown by

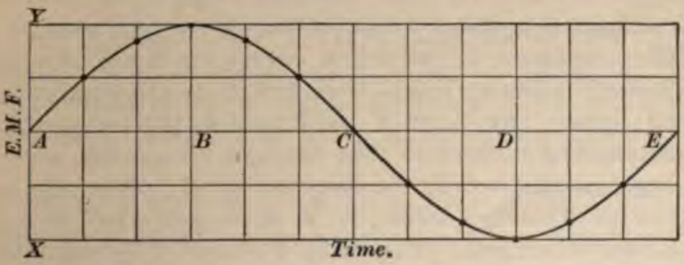


FIG. 14.

the use of the cross-section paper. The sum of the divisions between *A* and *E* represents the time occupied by the coil in making one complete revolution; the divisions between *A* and *Y* represent the E. M. F. which tends to send a current in one direction through the coil, as in the first half of the revolution, and the divisions between *A* and

X represent the E. M. F. which tends to send a current through the coil in an opposite direction, as in the last half of the revolution. The divisions between the curved line and the line *A E*, or **base line,** give the E. M. F. that is being generated in the coil at any instant during the revolution, and the direction in which the E. M. F. tends to act depends upon whether this E. M. F. falls above or below the base line *A E*. For convenience, let the direction in which the E. M. F. tends to act in the first half of the revolution be called the **positive** (+) **direction,** and in the last half the **negative** (–) **direction.** For example, the E. M. F. that is generated in the coil when it has revolved three-quarters of a revolution is represented by the distance between *D* and the curved line, which, in this case, is two divisions; and since these divisions are below the base line, the direction in which this E. M. F. tends to act is negative.

13. In Fig. 15, instead of connecting the external circuit directly to the ends of the coil, suppose the wires *o* and *p* to be brought to two brushes *r* and *s*, which lie in a horizontal position and bear on the two *collector rings x* and *y*, respectively. These collector rings, it will be seen, are connected to the two ends of the coil; *x* to *a* and *y* to *b*.

The resistance of the entire circuit, including the coil, ammeter, collector rings, and brushes, is comparatively small; hence, any E. M. F. generated in the coil causes a corresponding current to flow through the circuit, and its strength is indicated by the ammeter *A. M.* When the coil begins to revolve, a feeble E. M. F. is generated in it, as previously described. This E. M. F. causes a corresponding current to flow through the circuit in a positive direction; as the E. M. F. becomes larger, the strength of current in the circuit becomes greater, and vice versa. After the coil is rotated one-half of a revolution and the direction in which the E. M. F. tends to act becomes negative, the direction of the current in the circuit is also reversed. If there is no self-induction to retard the rise and fall of the current in the circuit, the strength of the current in the circuit at any instant is exactly proportional to the E. M. F. that is being generated in the coil at that moment; for, according to Ohm's law, the strength of current in any circuit is equal to the E. M. F. generated in that circuit, divided by its resistance. The rising and falling and also the reversing of the current in all parts of the circuit for each revolution, therefore, can be represented graphically on cross-section paper in the same manner as previously described for the E. M. F. Fig. 16 represents the rising, falling, and reversing of the current in the circuit for three complete and consecutive revolutions of the coil; the divisions between

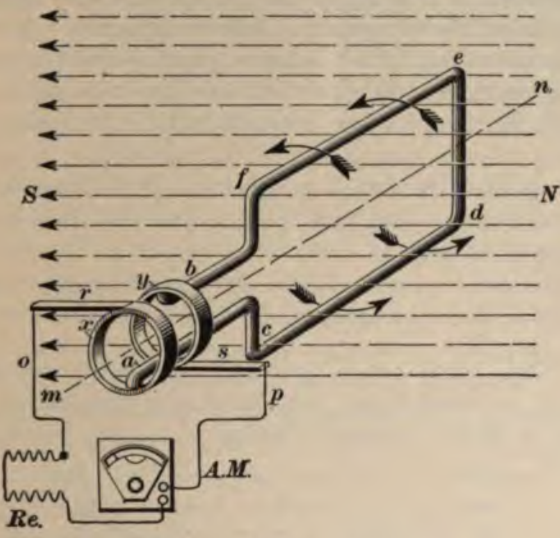


FIG. 15.

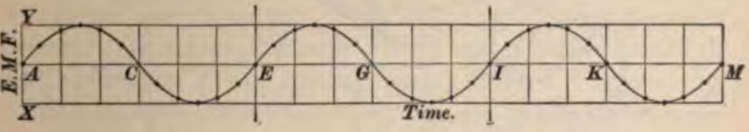


FIG. 16.

A and *E*, *E* and *I*, and *I* and *M* represent the time of each revolution, respectively. The divisions between the base line *A M* and the curved line above the base line represent the strength of current in the circuit when the direction of flow is positive, and those below represent the strength of current when the direction of flow is negative. Revolving the coil, therefore, at a constant speed generates a current in the circuit, which, in every complete revolution, rises gradually to a maximum strength and falls to zero in one direction, then is reversed, and the same effect is produced in the opposite direction. In other words, the current in the circuit *alternates* from one direction to the opposite direction in each revolution.

An electric current of this character flowing through a circuit is termed an **alternating current.**

14. The next step is to demonstrate the principle of changing, or *commuting*, this alternating current into a *continuous*, or *direct*, current; that is, a current which always flows in the same direction through the external circuit. In Fig. 17, the two ends of the coil are fastened to two

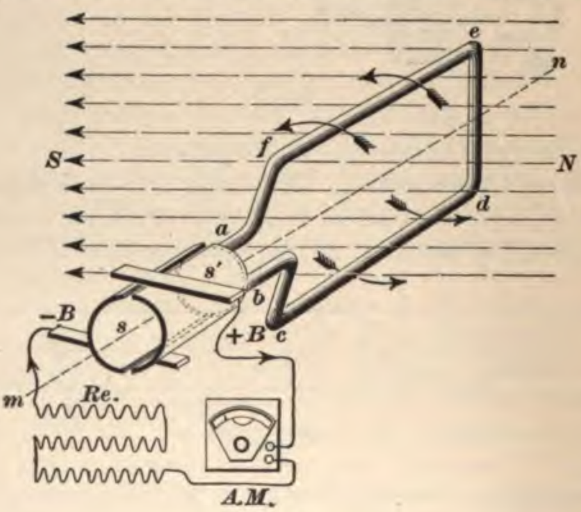


FIG. 17.

halves *s* and *s'* of a metallic tube. These halves are called **segments**, and in this case are separated by a small air space, the rigidity of the coil holding them apart. The combination of the two segments, or, in fact, any number of segments held together in this position, is called the **commutator.** Two copper strips $+B$ and $-B$, called **brushes**, press against the segments, and are held in a horizontal position while the coil is rotated. The brushes rub, or *brush*, against the segments and make electrical contact only.

When the coil is in a vertical position, as represented in the figure, both brushes rest against both segments; but as soon as the coil starts on the first half of a revolution in the direction indicated by the arrows, the brush $-B$ leaves segment *s'* and rubs only against segment *s*; brush $+B$ leaves segment *s* and rubs only against segment *s'*. As previously described, the electromotive force that is generated in the coil during the first half of a revolution causes a current to flow from *a* through the coil to *b*, and from *b* through the external circuit to *a* again, making *b* the positive end of the coil. Hence, in this case, $+B$ is the positive brush, and the current in the external circuit flows in the direction indicated by the arrowheads. As the coil starts on the last half of a revolution, the direction of the current in the coil changes, and *a* becomes the positive end of the coil. But the current in the external circuit continues to flow in the same direction as in the first half of the revolution, and $+B$ remains the positive brush. For, at the beginning of the second half of a revolution, when end *a* of the coil becomes positive, $-B$ leaves segment *s* and makes contact with *s'*, and $+B$ leaves *s'* and makes contact with *s*. Hence, the current in the external circuit, during a complete revolution, flows from the positive brush $+B$ through the ammeter *A M* and the resistance *Re* to the negative brush $-B$; that is, the current in the external circuit flows continually in the same direction, while the current in the coil itself flows in two directions during every revolution. But the strength of the current in the external circuit is by

no means constant; it rises from zero to a maximum strength and falls again to zero twice in every revolution, but always in the same direction. The effect is graphically shown in Fig. 18 by the use of cross-section paper, where the divisions between *A* and *E*, *E* and *I*, and *I* and *M* represent the time occupied by the coil in rotating each revolution, respectively, and the vertical divisions between the base line *A M* and the curved line represent the strength of

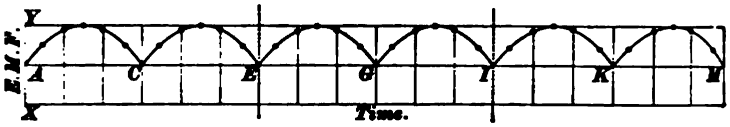


FIG. 18.

the current in the external circuit at every instant during the three revolutions. The effect is produced continually in the external circuit if the coil is rotated at a constant speed. These impulses in the strength of the current give it the name of pulsating current.

A consideration of the preceding paragraphs will show the student that direct-current dynamos require commutators, while alternating-current dynamos employ only collector rings.

13. In Fig. 19, two separate coils are placed in a magnetic field at right angles to each other. Four metallic segments s, s', s'', and s''' are cut from a cylindrical ring to form the commutator, and are separated from one another by small air spaces; the two ends of each coil are connected to two opposite segments in such manner that an imaginary diameter connecting the two segments together would lie at right angles to the plane of their coil, as shown in the figure. The metallic brushes $+B$ and $-B$ rub against the commutator, touching the two segments diametrically opposite each other. A line drawn through the center of the commutator connecting the contact ends of the two brushes must be at right angles to the direction of the lines of force of the magnetic field in which the coils are rotated. As the two coils and commutator are rotated in the direction indicated by the arrows, the two brushes rub against the segments consecutively and always make contact with the two opposite ones. The brushes are connected to an exernal circuit consisting of the ammeter *A M* and the resistance *Re*. At the position of the coils in the figure, the brushes are rubbing against the segments *s* and *s*″, which

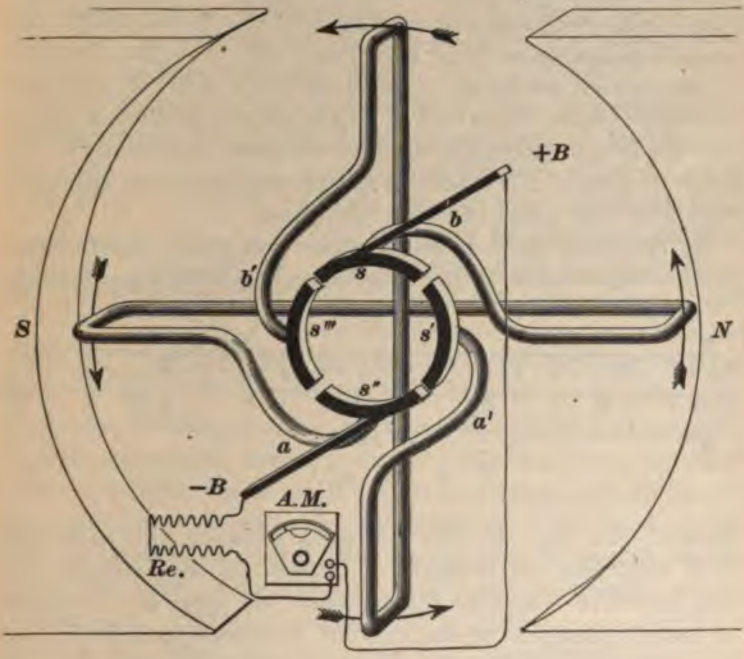


FIG. 19.

are connected to the ends of the horizontal coil. From previous experiments, it will be seen that at this position the horizontal coil is generating a maximum E. M. F., which tends to send a current from *a* through the coil to *b*; hence, the current is flowing in the external circuit from $+B$ to $-B$. After the coils and commutator are rotated one-eighth of a revolution from this position, and the E. M. F. in the coil begins to fall, the brush $+B$ passes from segment *s* to segment s', and brush $-B$ passes from s'' to s'''. The E. M. F. that is being generated in the vertical coil when the brushes pass to segments s' and s''' is nearly maximum. Consequently, the strength of the current which has been flowing in the external circuit from the other coil does not decrease to zero; it only diminishes a small amount before the segments of the next coil make contact with the brushes, when it begins to increase again. It will be seen that during one complete revolution of the moving parts, the brushes passed over four segments; also that the direction of the current produced is *from* the coils *to* brush $+B$, and *into* them *from* brush $-B$. These actions produce a direct current in the external circuit which flows continually in the same direction, but whose strength fluctuates, or changes, regularly four times in every revolution.

By resorting again to the cross-section paper, the fluctuations of the current in the exterior circuit can be graphically shown. In Fig. 20, the divisions between the base line $A\ M$ represent the strength of current in the external circuit for three complete revolutions. So long as the speed of rotation is uniform, the current decreases to a little less than three-quarters of its maximum strength, provided, of course, the resistance of the external circuit is not altered; the dotted curved lines indicate how the strength of the current would fall to zero if only one of the coils were used.

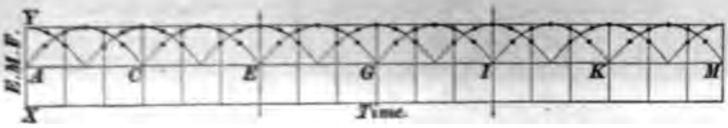


FIG. 20.

The strength of such currents can be made more uniform and the pulsations less noticeable by using several coils connected to the segments of a commutator, the planes of the coils being placed at equal angles from one another. A continuous current of uniform strength is known as a constant current.

16. It has already been stated that the *permeability* of iron is much greater than that of air; or, in other words, if a piece of iron were inserted in a magnetic field, the number of lines of force in the field would be greatly increased. Hence, if the coils are wound around a cylindrical drum of iron, as shown in Fig. 21, the number of lines of force passing through the coils is increased, and the E. M. F. that is generated is greater, since the E. M. F. is proportional to the rate of cutting of the lines of force. The coils are entirely insulated from the iron core by some non-conducting material, such as cloth, mica, or paper; otherwise, they would be short-circuited on the core; that is, the current would flow through the iron instead of passing into the external circuit. The other conditions remain unchanged; i. e., the lines of force have the same direction as in the previous cases, and remain in one position while the coils are revolved. The core should not be made of one solid mass of iron; for, if such were the case, the core, when rotated, would act as a large closed conductor, cutting lines of force at right angles. The E. M. F. generated in the core would cause **local,** or **eddy,** currents to flow through the iron itself, heating it and uselessly dissipating a large amount of energy. An idea of how these

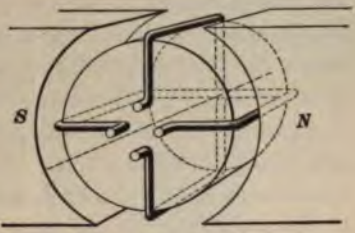


FIG. 21.

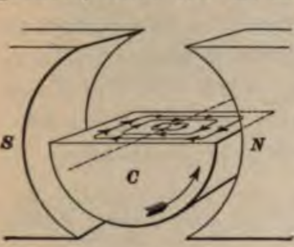


FIG. 22.

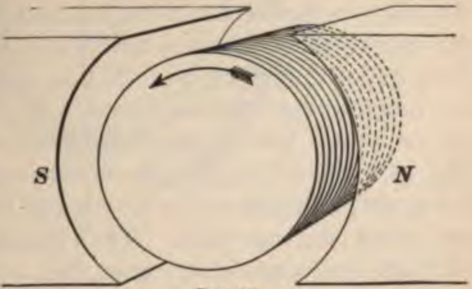


FIG. 23.

eddy currents would circulate in a solid iron core can be formed from Fig. 22. *C* represents the solid iron core, the top half of which is cut away. The curved lines and arrowheads show the direction in which the eddy currents would flow if the core were rotated in the direction indicated by the large arrow. To overcome this difficulty, the core is made of a large number of round, thin iron plates, or disks, each disk being insulated from the adjacent ones by some non-conducting material, such as tissue paper, insulating japan, or simply by the oxide formed on the surface of the disk during the process of its manufacture. The disks should be fastened together in such a manner that, when rotated in a magnetic field, their flat surfaces are parallel to the direction of the lines of force and to the direction of rotation, as shown by Fig. 23. Dividing the core into disks in no way diminishes the magnetic permeability of the iron, and for all practical purposes, it prevents the eddy currents from flowing. A core made in this way is said to be **laminated.**

17. Iron cores are generally made in two styles: **drum** or **ring.**

A drum core may be defined as a laminated cylinder, the length being generally greater than the diameter, such as shown in Fig. 23.

A ring core may be defined as a laminated rim of rectangular cross-section, such as *R* in Fig. 24.

An iron core inserted between the poles of a magnet not only increases the total number of lines of force from the magnet, but attracts nearly all the stray lines of force from the surrounding air; that is, the lines of force prefer to complete their circuit through iron rather than through air or other non-magnetic substances. For example, in Fig. 24, an iron ring *R* is placed between the poles *N* and *S* of a magnet; the lines of force pass out from the north pole *N* and enter the iron ring. When passing across the air gap, they are uniformly distributed, but after entering the ring, they crowd together and remain in the iron as long as possible. If the total number of the lines of force is large in mparison with the cross-sectional area of the iron ring on *y*, a few will pass through the air in the inside of the ring, shown in the cut; but in most cases the number of such ray lines is not large enough to be considered. Conse- ently, in Fig. 25, if a loop of insulated wire *a b c d* is ound around the iron ring, and the ring and loop are

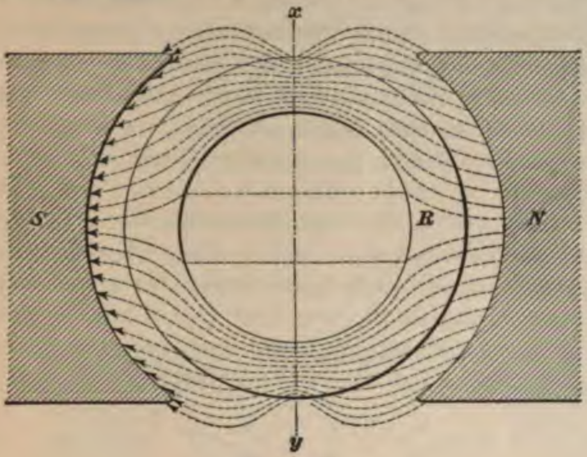


FIG. 24.

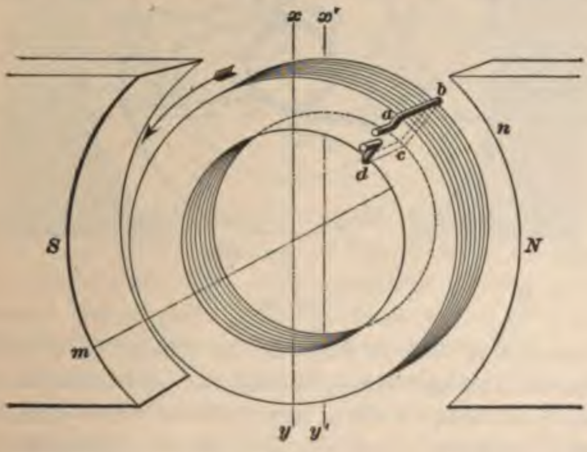


FIG. 25.

rotated on a central axis *m n* like the rim of a flywheel, only that part of the loop from *a* to *b* is cutting lines of force; the rest of the loop, from *b* to *c* and from *c* to *d*, is inactive in relation to the lines of force. From the thumb-and-finger rule it will be seen that the E. M. F. generated in the side *a b* of the loop tends to send a current from *b* to *a* during the first half of the revolution from *y y'* to *x x'*, and in the opposite direction during the last half.

18. No current will flow from the loop through the external circuit when the ring is made of some non-magnetic substance, as will be understood from the following explanation: Imagine the iron ring to be moved from the field without disturbing the loop; then, imagine the loop to be rotated around the axis *m n* in precisely the same path as before. The lines of force in the field are now uniformly distributed, and as the loop moves, the part between *c* and *d* will cut the lines of force at approximately the same rate as the part between *a* and *b*. But the electromotive forces generated in the two parts tend to oppose each other; that is, the E. M. F. generated between *a* and *b* tends to act away from *b*, and that generated between *c* and *d* tends to

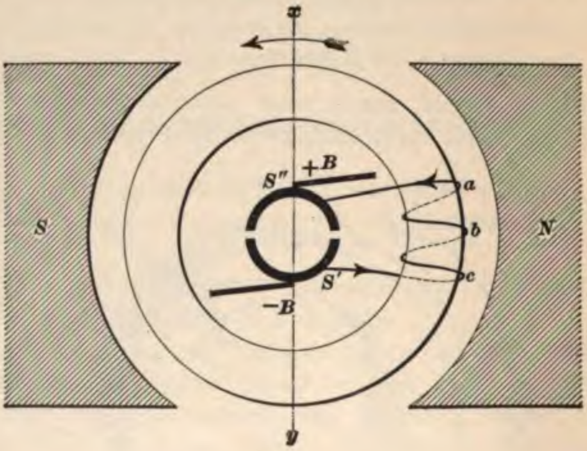


FIG. 26.

act away from *c*. Hence, there is no difference of potential between the ends *a* and *d*, and no current will flow through an external circuit.

After replacing the iron ring again, suppose the insulated wire to be wound around it several times, as represented in Fig. 26, and the ends of the coil connected to two metallic segments S' and S''. By applying the rule, it will be seen that the electromotive forces generated in the separate turns at *a*, *b*, and *c* are added together; that is, the difference of potential between the brushes $+B$ and $-B$ is the sum of the electromotive forces generated in the separate turns. The current obtained from such a coil is *pulsating*. For all practical purposes, the total E. M. F. generated by such a coil is directly proportional to the number of turns. For example, if a coil of 1 turn generates 2 volts at a certain position and angular velocity, then a coil of 4 turns will generate 8 volts under the same conditions, and so on. But the turns in each coil must be approximately close together. For, if the coil is wound over a large portion of the ring, some of the turns, at one position of the coil, will be cutting the lines of force as they pass out from the north pole, while other turns will be cutting the lines of force as they enter the south pole, the electromotive forces generated in the

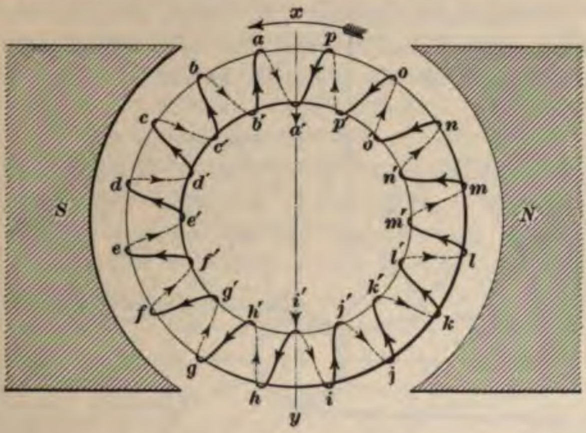


FIG. 27.

two cases being opposed to each other. This action will be readily understood by winding the entire core with one large coil of several turns and connecting the two ends of the coil together, as represented in Fig. 27. This is known as a *ring* winding, or one in which the conductors are wound in the form of a helix on a ring core. At the instant the ring and coils reach the position shown in the figure, the E. M. F. generated in the separate turns tends to act in the direction indicated by the arrowheads upon the winding. No current can flow around the coil, because the electromotive forces generated in the two halves act toward each other at a' and away from each other at i'.

19. It is possible, however, to obtain a continuous current from the coil by the addition of a commutator with several segments, as will presently be seen. If the ends of a voltmeter are touched to a' and i' during the instant the coil occupies the position in Fig. 27, a difference of potential between the two points will be indicated, a' being the positive point and i' the negative. Hence, if these two

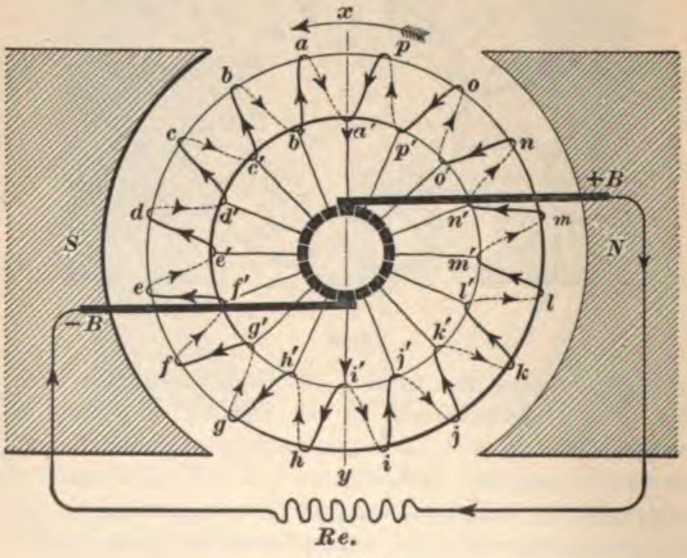


FIG. 28.

points are connected to an external circuit, a current will flow through it from a' to i', while the coil is at the position shown in the figure. As soon, however, as the coil is rotated about one-sixteenth of a revolution, the difference of potential between a' and i' will begin to fall, and the greatest difference will now be found between p' and h'. About another sixteenth of a revolution will bring the greatest difference of potential between o' and g', and so on. In short, as the coil is rotated, the greatest difference of potential will always be found between any two turns situated diametrically opposite each other when they pass through the vertical diameter $x\,y$. The next operation is to provide some means to utilize this difference of potential between each pair of turns as they arrive in a vertical position. This is accomplished by connecting each turn to a separate segment of a commutator by a small conductor, and allowing two brushes to rub against the commutator at two points diametrically opposite each other on the vertical diameter $x\,y$, Fig. 28. From an examination of the figure, it will be seen that the two halves of the coil are connected in parallel or multiple; that is, the current divides at i', one half passing through the turns i, j, k, l, etc. and the other through h, g, f, e, etc. to a', where it again unites. The maximum E. M. F. that is obtained from the coil is equal, therefore, to the E. M. F. generated in one-half of the coil. This statement will be better understood by comparing the coil to a battery of voltaic cells connected in multiple-series. For example, in Fig. 29, the separate cells from a to h, inclusive, correspond to the separate turns on one half of the coil, and the cells from i to p correspond to the turns on the other half. The total E. M. F. of the above battery is equal to the E. M. F. of either of the two sets which are connected in parallel; and the total E. M. F. of either of the two sets is

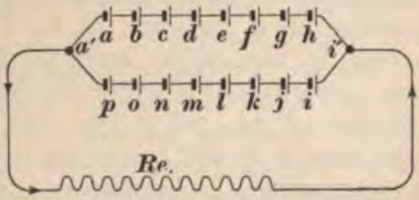


FIG. 29.

the product of the E. M. F. of 1 cell and the number of cells which are connected in series, as from *a* to *h*, inclusive.

If a comparatively large number of turns and segments is used, the current flowing from $+B$, Fig. 28, through the external circuit to $-B$ will be practically continuous, that is, non-pulsating; the fluctuations caused by the brushes when passing from one segment to another are extremely minute, and produce no appreciable change in the strength of the current in the external circuit.

20. A conductor wound upon a core in the manner shown in Figs. 27 and 28 is termed a **closed-coil winding**, since all the turns are connected together in one *continuous*, or *closed*, coil, and the current is obtained from it by tapping into each turn or set of turns. In the case where the turns or sets of turns are separate and distinct from one another and their ends are connected to opposite segments of a commutator, as in Figs. 19 and 26, the winding is termed an **open-coil** winding.

21. A *closed-coil winding* can be applied to a cylindrical drum core, as previously described, and a continuous non-pulsating current obtained from the brushes, as in the case of the ring core. The method of winding is somewhat similar to that of the ring, and each turn or set of turns is tapped into and connected to the segment of a commutator by a separate lead, as will be seen from the diagram, Fig. 30. This is known as a drum winding, or one in which the conductors are wound longitudinally upon the surface of a drum core. A drum winding may also be applied to a ring core, as will be seen. The conductor is started at any convenient place on the core, as, for example, at *a*, and wound across the face of the drum to the rear end; then, wound nearly diametrically across the end, and from there along the face of the core to the front end at *a'*. From *a'*, the conductor is wound across the front end to a point somewhat in advance or behind the original starting point *a*, as, for example, to *b*; from *b* it makes another complete turn in like manner, which is followed by a third, and so on, until the last turn is connected to the first by joining the two ends of the coil together at *a*. A separate lead *L* is tapped into the conductor at every complete turn where it is wound across the front end of the core and connected to the separate segments of a commutator. From an examination of the diagram, it will be seen that only a part of the wires on the face of the drum are cutting the lines of force as they enter and pass out of the core at any one instant during a revolution. At the position represented, the wires *e'*, *a*, *f'* and *b'*, *e*, *a'* are the inactive ones, so far as the lines of force are concerned; but they still perform the important function of completing the circuit for the current. The parts of the core where the wires are not cutting the lines of force as the core is rotated are called the **neutral spaces**; and the two opposite parts of the commutator to which the coils are connected are called the **neutral points** of the commutator. Each individual wire becomes inactive twice during every revolution and passes through two neutral spaces; but this fact does not change the positions of the neutral spaces—they lie on an imaginary diameter approximately

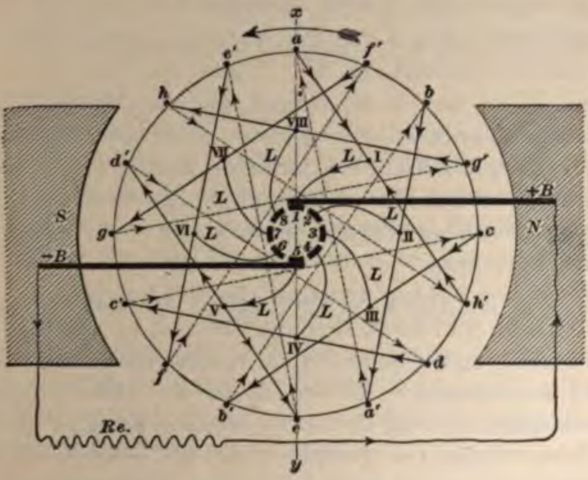


FIG. 30.

perpendicular to the lines of force. This same effect takes place in the commutator, i. e., each segment passes through two neutral points during one complete revolution, but the neutral points remain in a fixed position relative to the neutral spaces of the core. The neutral segments of the commutator, at any instant during a revolution, are those segments which are connected to the wires passing through the two neutral spaces at that instant. The neutral points, however, can be shifted to different points around the commutator by changing the leads from the coil to the segments. For example, in Fig. 30, the two neutral points lie opposite each other on the commutator along the vertical diameter $x\,y$. But if the lead from *I* is connected to segment No. 7, instead of No. *1*, and the lead from *II* to segment No. *8*, and so on around the commutator, then the two neutral points will lie opposite each other on the commutator along a horizontal diameter, and in order to collect any current from the commutator, the brushes $+B$ and $-B$ must be shifted around a quarter of a revolution to these new neutral points.

The current flowing through the winding divides at one neutral space and flows through the coil in opposite directions, uniting again at the other neutral space, as indicated by the arrowheads. According to the thumb-and-finger rule, the current in all the active wires in front of the north pole flows along the periphery of the core towards the observer; that in the wires in front of the south pole flows away from the observer.

22. The next step is to determine the magnitude of the E. M. F. in volts generated in a closed coil. As previously stated, the E. M. F. generated in a conductor cutting lines of force at right angles is proportional to the *rate of cutting*. Consider the case of a single conductor moving across a magnetic field in which the total number of lines of force is known; the rate of cutting is equal to the total number of lines of force cut by the conductor divided by the time required to cut them. This may be expressed in the form of an equation: thus, *rate of cutting* $= \frac{N}{t}$, where N is the total number of lines cut and t is the time required to cut them. By definition, *one volt* is that E. M. F. generated in a conductor when it is cutting lines of force at the rate of one hundred million (100,000,000) per second. Hence, $E = \frac{N}{10^8\,t}$, where E is the E. M. F. in volts and t the time in seconds, since $100,000,000 = 10^8$.

For example, suppose a magnetic field contains 4,500,000 lines of force, and a conductor cuts the total number in the same direction in 1.5 seconds. The E. M. F. that is being generated in the conductor is equal to .03 volt, since $E = \frac{N}{10^8\,t}$ $= \frac{4,500,000}{100,000,000 \times 1.5} = .03$ volt.

When two or more conductors are cutting lines of force at equal rates, the E. M. F. obtained by connecting them in series is equal to the E. M. F. developed by one conductor multiplied by the number of conductors. Consequently, if S is the number of conductors in series, then $E = \frac{N\,S}{10^8\,t}$, where E is the total E. M. F. in volts that can be obtained from S conductors cutting N lines in t seconds. For example, if 8 conductors are moved across the magnetic field containing 4,500,000 lines of force in 1.5 seconds, and they are connected in series, then $E = \frac{N\,S}{10^8\,t} = \frac{4,500,000 \times 8}{100,000,000 \times 1.5}$ $= .24$ volt.

Next, imagine these 8 conductors to be moved across the magnetic field in the same direction at the rate of 30 times per second for 1.5 seconds; then, the number of lines cut in one second is $4,500,000 \times 30 = 135,000,000$, and the total number of lines cut in 1.5 seconds is, therefore,

$$135,000,000 \times 1.5 = 202,500,000. \quad \text{Hence,}$$

$$E = \frac{(N\,n\,t)\,S}{10^8\,t} = \frac{202,500,000 \times 8}{100,000,000 \times 1.5} = 10.8 \text{ volts.}$$

Here $n =$ the number of times per second that one conductor cuts the lines of force.

But, in general, the E. M. F. that is obtained from several conductors connected in series moving continually across the same magnetic field at a constant number of times per second is independent of the length of time the operation is continued. For, in the above equation, $E = \frac{(N n t) S}{10^8 t}$, the two t's cancel each other, leaving the equation $E = \frac{N S n}{10^8}$. In the above example, for instance, so long as the 8 conductors are moved across the magnetic field at the rate of 30 times per second, the E. M. F. generated in them is always 10.8 volts, no matter whether the operation is continued for 1.5 seconds or for 1 hour. The time of 1.5 seconds was used merely to make the demonstration clearer by using a specific value for t.

23. The equation $E = \frac{N S n}{10^8}$ can now be applied with some modifications to the closed-coil conductor wound upon either the ring or drum core. The ring core, Fig. 28, will first be considered. In the equation, E is the maximum E. M. F. in volts that is obtained from the brushes $+B$ and $-B$ when the core is revolved; N is the total number of lines of force passing from the north pole through the core to the south pole. Each wire, therefore, on the periphery of the core cuts the total number of lines twice during every revolution; or, in other words, each outside wire cuts $2\,N$ lines of force per revolution. S is the number of outside wires on the periphery through which the current flows in *series*, and n is the number of complete revolutions per second of the core. Therefore, the maximum E. M. F. in volts that is obtained from the brushes is found by the formula

$$E = \frac{2\,N S n}{10^8}. \qquad (1.)$$

That is to say, *the E. M. F. obtained from a number of* *conductors connected in series and moved across a magnetic field is equal to twice the number of lines of force multiplied by the number of conductors in series and by the revolutions per second of the core, divided by* 100,000,000. For example, assume the total number of lines N passing from the north pole through the core to be 3,000,000, or $N = 3{,}000{,}000$. In the diagram, Fig. 28, there are 8 outside wires in series, or $S = 8$. If the core is rotated at 2,100 revolutions per minute, $n = \frac{2{,}100}{60} = 35$ revolutions per second. Substituting the values in the formula gives $E = \frac{2\,N\,S\,n}{10^8}$ $= \frac{2 \times 3{,}000{,}000 \times 8 \times 35}{100{,}000{,}000} = 16.8$ volts, or the difference of potential between the brushes $+B$ and $-B$ on open circuit. The difference of potential between the brushes when the external circuit is closed is somewhat smaller than when no current is flowing; because, as in the case of the voltaic cell, a part of the total E. M. F. developed is required to overcome the internal resistance of the coil itself.

The formula $E = \frac{2\,N\,S\,n}{10^8}$ holds equally true for the drum core, Fig. 30. In both cases, the number of outside wires through which the current flows in *series* is equal to one-half the total number of outside wires. Hence, by using the same magnetic field and rotating the cores at equal speeds, the E. M. F. generated in both cases will be equal.

24. The foregoing articles demonstrate the elementary principles and physical theory of a *dynamo*. A **dynamo,** therefore, is a machine for converting mechanical energy into electrical energy by electromagnetic induction. It has three essential features, viz.: (1) a magnetic field; (2) a conductor, or several conductors, called an **armature,** in which the electromotive force is generated by some movement relative to the lines of force in the magnetic field; and (3) a *commutator*, or a *collector*, from which the current is collected by two or more conducting brushes.

In all dynamos, the magnetic field is produced either by a permanent magnet or by an electromagnet, and they are classified accordingly; for present purposes, however, it is sufficient to consider only the uniform magnetic field lying between the poles of some large magnet. In the preceding article, the armature core and commutator were assumed to be fastened rigidly to a shaft and the shaft supported by suitable bearings in such a position that the core would rotate in the magnetic field with its axis of rotation at right angles to the lines of force. The shaft with core and commutator was assumed to be rotated by some exterior mechanical power. The armature conductors were wound directly upon the core and rotated with it. If it were not for mechanical considerations, however, only the armature conductors would need to be rotated; the core could remain stationary.

ARMATURE REACTIONS.

25. When the current is flowing through the armature conductors, it produces several effects upon the magnetic field; and the field, in return, reacts upon the current. These effects will be considered before describing the typical forms of dynamos.

Consider the case of a single conductor in which a current is flowing from a voltaic battery or a continuous-current dynamo, and a magnet. It has been shown that a magnet and a conductor conveying an electric current exert a mutual force upon each other; or, in other words, each tends to produce motion in the other. In the case of a compass placed over or under a conductor conveying a current, if the magnetic needle be held rigidly and the conductor be allowed to swing freely in a horizontal plane, it would tend to place itself at right angles to the length of the needle. In general, *when a conductor conveying an electric current is placed in a magnetic field, the conductor will tend to move in a definite direction and with a certain force, depending* *upon the strength and direction of the current, and upon the direction and density of the lines of force in that field.*

Imagine that a conductor conveying an electric current is placed across a uniform magnetic field, and that it lies in a position at right angles to the lines of force. For example, the diagram in Fig. 31 represents a cross-sectional view of a uniform magnetic field, the dots representing the ends of the lines of force and the heavy line a conductor conveying a current. The direction of the lines of force is assumed to be downwards, that is, piercing the paper; or, in other words, the observer is looking along the lines of force toward the face of a south magnetic pole. The lines of force along the conductor from the top to the bottom of the magnetic field act upon the current in the conductor with equal intensities, and all tend to move the conductor in the same direction. This action, if the magnetic field is uniform, is similar to that of a uniformly distributed load upon a beam tending to move or bend it.

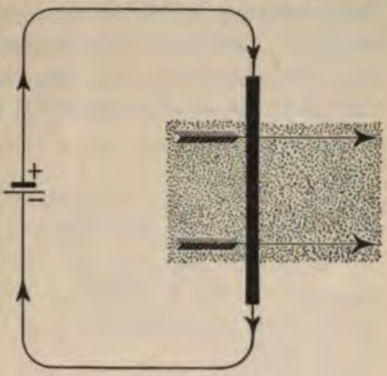


FIG. 31.

The motion imparted to the conductor is perpendicular to the lines of force, and also perpendicular to the flow of current in the conductor. To fulfil these conditions, therefore, the conductor in Fig. 31 must tend to move bodily either to the right or left across the field; in which of these two directions it moves depends upon the relative direction of the lines of force with the direction of the current in the conductor. In this case, if the direction of the lines is downwards, piercing the paper, and the current flows *from* the top *to* to the bottom of the diagram, as indicated by the small arrowheads, the conductor will tend to move from the left to the right in the direction in which the two large arrows are pointing. If the direction of the lines of force only is changed, the conductor will tend to move in the opposite direction, i. e., from the right to the left; or, if the direction of the current in the conductor only is reversed, the conductor will tend to move also from right to left across the field. But should both the direction of the lines of force and the direction of the current in the conductor be changed, the conductor would still tend to move from left to right.

26. There is a convenient thumb-and-finger rule for remembering the direction of motion imparted to a conductor conveying an electric current when placed in a magnetic field; it is similar to the rule for generated currents, with the exception that the *left hand* is used instead of the *right*.

Rule.—*Place thumb, forefinger, and middle finger of the left hand each at right angles to the other two; if the forefinger points in the direction of the lines of force and the middle finger points in the direction toward which the current flows, then the thumb will point in the direction of movement imparted to the conductor.*

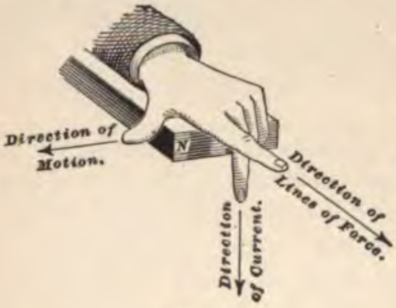


FIG. 32.

For example, in Fig. 32, if a vertical conductor in which a current is flowing downwards is placed in front of the north pole *N* of a magnet, it will tend to move in the direction as indicated by the thumb.

27. Comparing the rule in Art. **8** with that given above, it will be seen that the two appear to oppose each other; or, in other words, the current which flows in the former case, according to the latter rule tends to oppose the motion of the conductor and move it in the opposite direction. This is exactly what takes place. When a conductor is moved across lines of force, an electromotive force is generated which tends to send a current in a definite direction; if the circuit is open and no current flows, it requires no force to move the conductor across the field; but if the circuit is closed and a current flows through the conductor, then the action of the lines of force on the current opposes the original motion and tends to stop or retard the conductor. The opposing force is proportional to the strength of current flowing in the conductor; that is, if a current of 10 amperes acts with a certain force, a current of 20 amperes will act with twice that force, and so forth. Hence, the stronger the current in the conductor, the greater will be the force necessary to keep the conductor moving in the original direction. The above explanation will be made clearer by the graphical illustration in Fig. 33. The diagram represents a cross-sectional view of a magnetic field, the direction of the lines of force being downwards, piercing the paper. If the conductor *c c'* be moved across the field by some exterior motive power in the direction indicated by the arrows *a*, *a*, a current will flow through the circuit in the direction indicated by the small arrowheads. The length of the arrows *a*, *a* may also serve to represent the magnitude of the force that moves the conductor. As the current flows through the conductor, the lines of force immediately react upon it, producing a *counter* force which tends to stop the conductor and move it in the direction indicated by the arrows *b*, *b*. The counter force would never actually move the wire in the direction of the arrows *b*, *b*, but it exerts a dragging effect

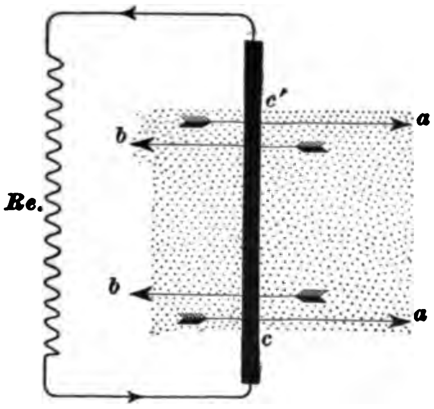


FIG. 33.

upon the conductor, which would reduce its speed and almost stop its motion if the exterior motive force were not increased. So long as the conductor is moved, the applied motive force is always larger than the counter force, as graphically represented by the relative lengths of the arrows.

28. The above principle explains the action of converting the mechanical energy into electrical energy in the dynamo. For example, suppose that an armature is rotated at a constant speed in a magnetic field by some exterior motive force, as, for instance, by a belt from an engine. If the armature is properly wound and connected to a commutator, an electromotive force is generated in the outside conductors on the core, causing a difference of potential between the brushes. If the brushes are not connected to an external circuit and no current is flowing through the armature, it requires no energy to rotate the armature, excepting a small amount to overcome the friction of the shaft in the bearings and the loss in the armature iron by eddy currents. By connecting the brushes to an external circuit, however, and allowing a current to flow through the armature, the conditions are altered. The lines of force react upon the current in the conductors, tending to rotate the core in an opposite direction and to retard its motion; the stronger the current, the greater will be the retarding effect. Hence, in order to keep the speed constant and to generate a constant E. M. F., more energy must be supplied to the pulley from the engine. This retarding effect of the current is known as the **counter torque** of a dynamo. The word torque, which will appear later in connection with the action of motors, means simply *turning* force.

It can be mathematically proved that the mechanical energy delivered to the armature from any exterior source is exactly equal to the electrical energy obtained from the armature plus the energy lost in mechanical friction, eddy currents in the iron, and other small losses, which will be described subsequently.

29. Besides producing a counter torque in the armature, the current tends to distort or crowd the lines of force from their original position in the magnetic field. This effect is termed **armature reaction,** and will be understood by investigating the magnetic effects of the current in the armature when the armature is removed from between the poles of the field magnets. In the diagram, Fig. 34, the current is flowing through the armature coil in the same direction as represented in Fig. 28. The current circulating around the armature coil in two directions acts as a magnetizing force upon the core and produces two electromagnets. According to the rule for magnetic polarity, the two magnets thus formed oppose each other at the two neutral spaces of the armature; that is, their like poles *N*, *N'* and *S*, *S'* tend to act in opposite directions at the neutral spaces. As previously explained, lines of force can never intersect each other, and will always produce consequent poles when acting in opposite directions at one place. Therefore, in this case, two consequent poles are formed in the core, one at each neutral space, as shown in the diagram. The polarity of the consequent poles, of course, depends upon the direction in which the coil is wound upon the core and the direction in which the current is generated. The same action occurs when the armature is rotated between the poles of a magnet and a current flows through the coil, although the conditions are somewhat altered. The lines of force from the magnet tend to pass through the core nearly at right angles to those produced by the current. The lines can never intersect,

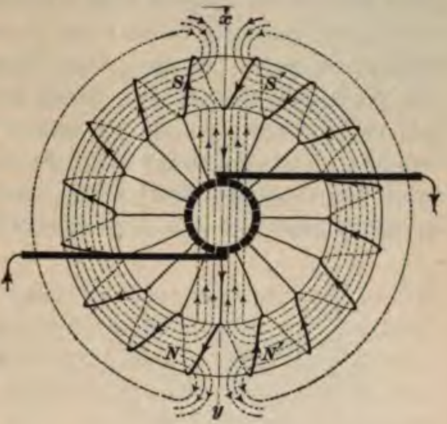


FIG. 34.

however, and they crowd and distort one another in order to coincide in direction. The lines that pass out from the north pole of the magnet tend to enter the core at the south consequent pole and to pass out from the core at the north consequent pole. At the same time, the south consequent pole is shifted toward the north pole of the magnet, and the north consequent pole toward the south pole of the magnet. The diagram in Fig. 35 represents the manner in which the magnetic field is distorted by the reaction of the armature current. In the case where the armature was removed from the magnetic field, the consequent poles coincided with the neutral space; but when the armature is replaced, as in the diagram, the consequent poles are shifted backwards against the direction of rotation, and the neutral spaces are moved forwards in the opposite direction, as indicated by the imaginary diameter *x y*. As the positions of the neutral points on the commutator depend upon the positions of the neutral spaces on the core, they are also shifted forwards in the direction of rotation when the current flows through the armature; hence, the brushes must be moved

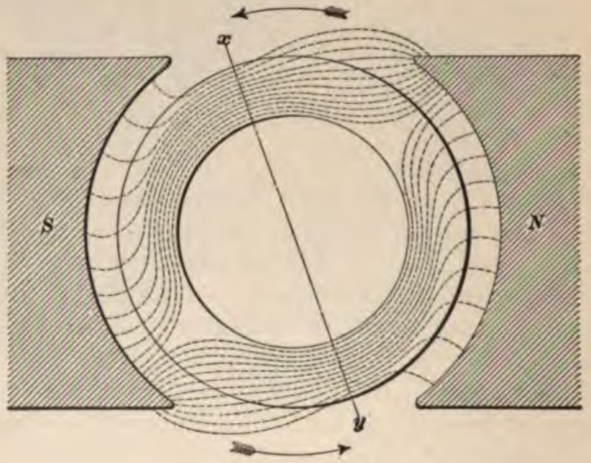


FIG. 35.

forwards in order to obtain the full E. M. F. generated in the coil. The stronger the current, the farther forwards the brushes should be shifted.

30. From the fact that in all dynamos of this character the relation of the lines of force, direction of rotation, and direction of current are constant, *the neutral spaces are always shifted forwards in the direction of rotation when the current becomes stronger*, no matter how the coil is wound upon the armature or in which direction the lines of force pass through the core.

These armature reactions are not confined entirely to the ring core, but are produced with the same effects in a drum-core armature, such as represented in Fig. 30. If the direction of the current is traced by the arrowheads upon the conductors, it will be seen that the current is flowing upwards along the face of the core in front of the north pole, as represented by the open circles, Fig. 36, and downwards in front of the south pole, as represented by the solid circles. The lines of force surrounding each conductor in which the current is flowing coincide with those around the adjacent conductors, forming a large number of long lines which pass through the core and produce consequent poles at the neutral spaces, as shown in Fig. 36. The direction of the lines of force around the conductors in which the current is flowing downwards corresponds with the movements of the

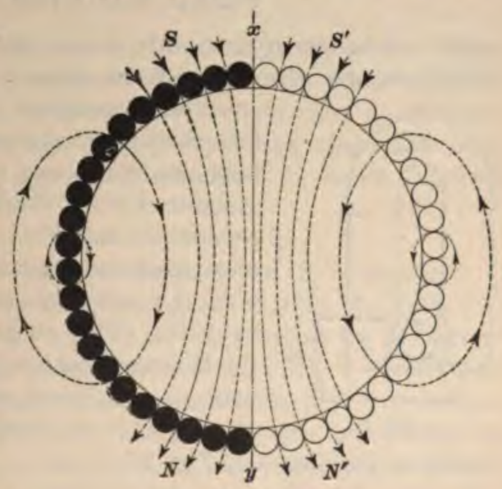


FIG. 36.

un ch, while the direction of the lines around the other cor rs is opposite. The lines from all conductors, however, co ide in direction in passing through the center of the core. When the armature is rotated between the poles of a gnet, the field is distorted and the neutral spaces shifted forwards in a manner similar to that described for the ring re.

31. Armature reactions not only distort the magnetic field, but also have a tendency to reduce the total number of lines of force from th and thereby diminish the E. M. F. generated in e. This effect, however, can be almost entirely y increasing the strength of the field, or, in other increasing the number of lines of force passing th core. This fact leads to the consideration of *field n*

FIELD M ETS.

32. It has been previously stated that the magnetic field in all dynamos is produced from either a permanent magnet or an electromagnet. A dynamo of the first class is called a **magneto-machine.** Such machines are necessarily small on account of the difficulty of making large permanent magnets; in fact, the field in most magneto-machines is produced by several permanent magnets placed side by side. The magnets are usually of the U-shaped pattern, of hard steel, and with a recess bored out between the ends of the poles to admit the armature, as shown in the diagram, Fig. 37.

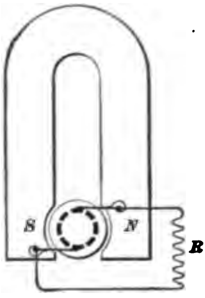


Fig. 37.

As the majority of magneto-machines are made for testing and signaling purposes where alternating currents can be used to advantage, the armature is wound with one large coil of wire, and the two ends of the coil are connected to two separate collector rings, as shown in Fig. 38. The alternating current is obtained from two brushes, one rubbing against each collector ring. The brushes can bear upon the collector ring at any position relative to the coil and the field magnets, since all parts of one collector ring are at the same potential in any instant. By comparing this coil with that in Fig. 13, it will be seen that the current obtained from the two brushes flows in two directions during every revolution.

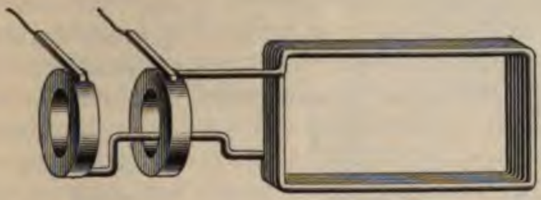


FIG. 38.

33. In nearly all dynamos furnishing current for lamps, power, and other commercial purposes, the magnetic field is produced by an electromognet. This class of dynamos is divided into various types, depending upon the manner in which the current is obtained to excite the field magnets.

34. The first class of machines to be considered is termed a **separately excited dynamo,** from the fact that its field magnets are excited or magnetized by a current from some external source, as, for instance, a voltaic battery, or another continuous-current dynamo. The connections of a separately excited dynamo are represented in Fig. 39. The magnetizing coils are wound around the cores of a magnet and connected to the terminals of a voltaic battery *B*. The exciting current flows from the battery around the cores of the field magnet in such a direction as to produce a closed magnetic circuit through the armature, and has no connection whatever with the current obtained from the brushes by rotating the armature. If the strength of the exciting current is not changed, the difference of potential between the brushes of the dynamo when the armature is rotated at a uniform speed remains constant so long as the external circuit is open; but when the external circuit is closed, the difference of potential gradually diminishes as the strength of current increases, owing to the internal resistance of the armature conductors and the reactions of the armature current on the field.

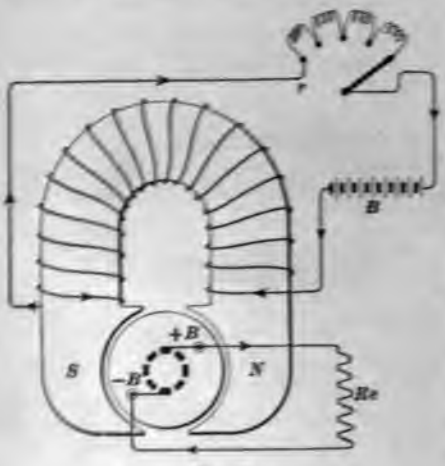


FIG. 20.

35. The **magnetizing force** is that which produces the lines of force in the magnet. Its strength is proportional to the strength of current flowing and to the number of coils or complete turns around which the current circulates. The total number of turns multiplied by the strength of the current in amperes will give the magnetizing force in **ampere-turns.** It has been proved that 10 amperes circulating around 20 turns exert precisely the same magnetizing force as 1 ampere circulating around 200 turns, or as 200 amperes circulating around 1 turn. In each of these cases, the magnetizing force is 200 *ampere-turns*. But the number of lines of force produced in an electromagnet is not directly proportional to the magnetizing force in *ampere-turns*. The strength of the magnet in lines of force depends upon the permeability of the magnetic substances used in the core. The permeability varies greatly in different magnetic substances, depending upon both the physical condition and the chemical composition of the substance. In general, *wrought iron*, *soft sheet iron*, and *steel* have greater permeability than cast iron, and, whenever available, should be used in field magnets in preference. The permeability, however, of all magnetic substances changes with every stage of magnetization. In all kinds of magnetic substances, the permeability decreases when the magnetism is increased beyond a certain limit. This tendency of the substance to become less permeable is called **magnetic saturation**; that is, the substance becomes *saturated* with lines of force and cannot hold any more. A limit is never reached where actual saturation takes place, but there is a limit beyond which it becomes impracticable to magnetize the substance. The practical saturation in wrought iron, soft sheet iron, and cast steel is when there are between 120,000 and 130,000 lines of force per sq. in. of sectional area of the iron, measured on a plane at right angles to the lines of force in the magnet. In gray cast iron, the practical saturation limit is from 60,000 to 70,000 lines of force per sq. in. Hence, when these limits are exceeded, it requires an enormous increase in the *ampere-turns* to produce a slight change in the number of lines of force in the magnet. In general, however, the field magnets of dynamos are designed with the density of the lines of force below the saturation limits, and it is safe to assume that any change in the strength of the current circulating around the magnetizing coils produces a corresponding change in the number of lines of force passing through the magnetic circuit. Consequently, if the strength of the current in the field coils of a *separately excited* dynamo is increased as the current in the armature becomes stronger, the E. M. F. obtained from the brushes will remain practically constant. This is usually accomplished by inserting an adjustable resistance box, or field rheostat r, in series with the battery and field coils, and decreasing the resistance as the difference of potential between the brushes tends to drop.

36. The second class of machines with an electromagnet is termed a **self-exciting shunt dynamo,** or simply a **shunt dynamo,** from the fact that the exciting current for the field magnet is furnished by the dynamo itself, the field coils being connected in *shunt* with the external circuit from the brushes. In Fig. 40, one terminal of the magnetizing coil is connected to the positive brush, and the other to a binding post on the field rheostat *r*; the negative brush is connected to the arm of the field rheostat. If the resistance of the rheostat is neglected or cut out, it will be seen that the total difference of potential exists between the terminals of the magnetizing coils when the dynamo is generating its maximum E. M. F. The magnetizing coils of a shunt dynamo, however, consist of a large number of turns of fine copper wire, thus making the resistance large in comparison with the difference of potential between the field terminals. In well-designed dynamos the resistance of the shunt coil is large enough to allow not more than about [illegible] of the total current of the dynamo to pass through the field coils; for, according to Ohm's law, the strength of current in amperes circulating around the field coils is equal to the difference of potential in volts between the brushes,

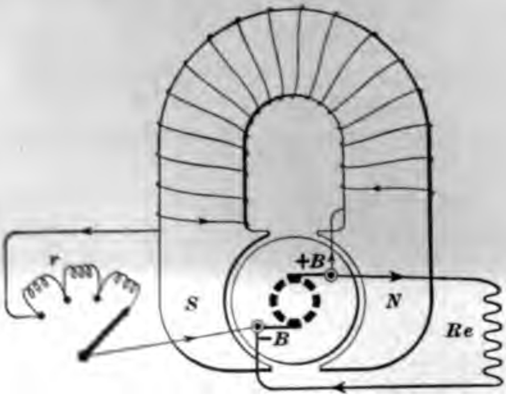


FIG. 40.

divided by the resistance in ohms in the field coil, neglecting the resistance of the rheostat. For example, suppose that the difference of potential between the brushes of a shunt dynamo is 500 volts when a current of 10 amperes is flowing from the armature. If 5% of this current is required to excite the field magnets, the strength of current circulating around the field coils is $10 \times .05 = .5$ ampere; and if E_e is the E. M. F. at the brushes, C_s is the current in the shunt field, and R_s is the resistance of the shunt field, then, according to Ohm's law, $R_s = \frac{E_e}{C_s} = \frac{500}{.5} = 1{,}000$ ohms.

37. When a shunt dynamo is rotated at a constant speed, an appreciable length of time elapses before the armature generates a maximum E. M. F. after the field circuit is closed, and in some cases a self-exciting dynamo will generate no E. M. F. until after it has been once separately excited. The starting of a dynamo to generate an E. M. F. is termed **picking-up,** or **building-up.** If the field circuit of a dynamo is open so that no current flows through the magnetizing coil, the armature will generate no E. M. F. when rotated, provided the field magnets are not permanent magnets; consequently, when the field circuit is closed on a shunt dynamo, no current will flow through the magnetizing coils, because there is no difference of potential between their terminals. But nearly all magnetic substances become permanent magnets in a slight degree after once being magnetized.

This permanent magnetism is called **residual magnetism,** since it *resides* in the metal after the magnetizing force has been removed. In general, soft iron and annealed steel retain only a small amount of magnetism, and in some cases the residual magnetism is imperceptible. Chilled iron and hardened steel retain residual magnetism in large quantities. Artificial or permanent magnets are made by placing a piece of hardened steel in a dense magnetic field or in contact with another magnet. Lodestone is the result of a natural residual magnetism. Iron and its alloys will also become slightly magnetized in the process of refining and working.

From these facts it will be seen that the cases where field magnets do not exhibit some residual magnetism are exceedingly rare. The armature conductors when cutting the lines of force of the residual magnetism generate a small E. M. F., and this E. M. F., in turn, causes a feeble current to circulate around the magnetizing coils when the field circuit is closed. The residual magnetism is, therefore, reenforced by the magnetizing effect of the current, which is followed by an increase in the E. M. F. generated, and that, in turn, by a stronger current in the field. These actions and reactions continue until a limit is reached where the fields become saturated with magnetism, and the number of lines do not increase at such a rapid rate; finally, both the E. M. F. and the current in the field become constant.

38. The difference of potential between the brushes of shunt dynamos gradually decreases as the current from the armature becomes stronger, on account of the internal resistance of the armature conductors and the reactions of the current on the field. The effect is even more marked than in separately excited dynamos, because a decrease in the difference of potential between the brushes causes a corresponding decrease on the field terminals, thereby weakening the current in the magnetizing coils. In order to compensate for the decrease in the E. M. F., a field rheostat r of comparatively high resistance is connected in the field circuit, and so adjusted that when no current is flowing in the external circuit only enough current flows through the field to produce the normal difference of potential between the brushes; this normal difference of potential between the brushes is kept constant as the load increases by gradually cutting out, or short-circuiting, the resistance coils of the rheostat.

NOTE.—The word *load* as used above is a common expression for *current* in dynamos generating a constant potential, and the student should become familiar with its use.

39. The third class of machines whose field magnets are excited by an electric current are termed **self-exciting series dynamos,** or simply **series dynamos.** The magnetizing coils of a series dynamo are connected directly in *series* with the external circuit; that is, all the current from the armature circulates around the magnetizing coils and flows through the external circuit. The connections of a *series* dynamo are shown in Fig. 41. The current starts from the positive brush $+B$, circulates around the external circuit Re, from thence through the magnetizing coils back to the negative brush $-B$. The action of a series dynamo differs widely from that of a shunt dynamo. In the first place, no E. M. F. is generated in the armature unless the external circuit is closed and a current flows from the brushes, that is, neglecting the small E. M. F. generated by the residual magnetism. In the second place, the difference of potential between the brushes depends upon the strength of current flowing from the armature. The E. M. F., however, is not directly proportional to the strength of the current unless the internal resistance and reactions of the armature are negligible. Compared with the coils on a shunt dynamo, the magnetizing coils of a series dynamo are made of a few turns of a large conductor. This is necessary, because the coils usually are required to carry the total current from the armature; the conductor is made large to carry the current without heating, and only a few turns are used to secure the proper degree of magnetization, since that is proportional to the *ampere-turns*.

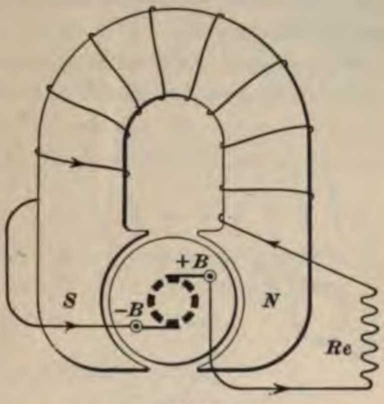


FIG. 41.

40. The E. M. F. of a series dynamo may be regulated in three different ways, viz.: (1) By controlling the strength of current in the external circuit as previously described; (2) by *short-circuiting*, or *cutting out*, part of the magnetizing coils; and (3) by *shunting* part of the current around the magnetizing coils.

The second of the above methods of regulating the E. M. F. will be understood from the diagram in Fig. 42. *S F* represents the magnetizing coils. *A* is a contact arm which travels in either direction along the line *x y*, one end making contact with the ends *a*, *b*, *c*, *d*, etc. of the series field, and the other being always connected to the external circuit *Re*. As the arm is moved toward *x*, the turns between it and *k* are cut out of circuit; that is, the current from the armature circulates around only those coils between the arm and *a*; if the strength of the current remains constant, the magnetizing force is thereby reduced. On the contrary, when the arm is moved toward *y*, additional turns are connected in circuit, and the magnetizing force is increased.

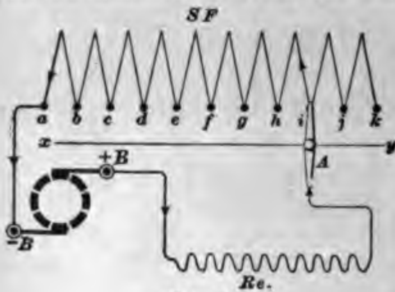


FIG. 42.

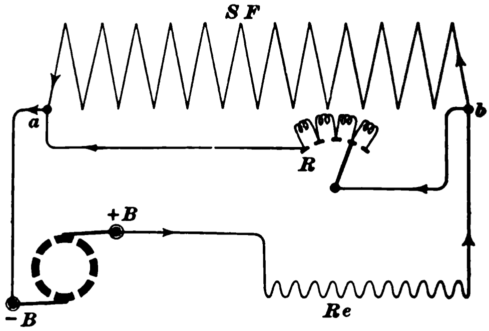


FIG. 43.

41. The third method of regulating the E. M. F. of a series dynamo changes the strength of the magnetizing current instead of varying the number of turns in the coil.

This effect is accomplished by connecting a resistance R, Fig. 43, in parallel or shunt with the series field coils $S\,F$, the current dividing between the two circuits inversely proportional to their separate resistances. Consequently, to increase the magnetizing force on the field magnets, the resistance R of the shunt circuit is increased, and vice versa. The total current from the armature is made to pass through the magnetizing coils by opening the shunt circuit entirely.

42. In the dynamo previously described, the regulation of the E. M. F. is not automatic; it is accomplished by a mechanical movement of an arm or contact. This movement is sometimes imparted by a magnet controlled by the current from the armature, but more often the E. M. F. is automatically regulated in the dynamo itself by a combination of the *shunt* and *series* magnetizing coils. Such machines are termed **compound,** or **shunt-and-series,** dynamos. In Fig. 44, the shunt coils consist of a large number of turns of fine insulated wire wound upon the core of the magnet. The series coils, consisting of a few turns of large insulated wire, are wound over the shunt coils. The main part of the current from the armature flows from the positive brush $+B$, through the external circuit Re, thence through the series coils to the negative brush $-B$. The two terminals of the shunt coils are connected to the two brushes $+B$ and $-B$, respectively. But the series and shunt coils are so wound that the currents in both circulate around the core of the magnet in the same direction when connected, as shown in the diagram. The action of both currents, therefore, is to produce the same polarity in the magnet,

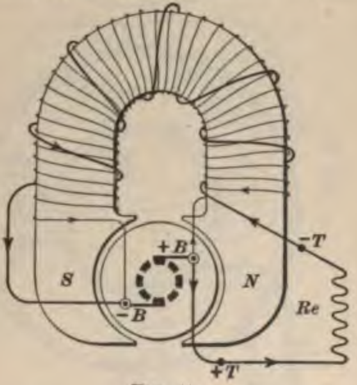
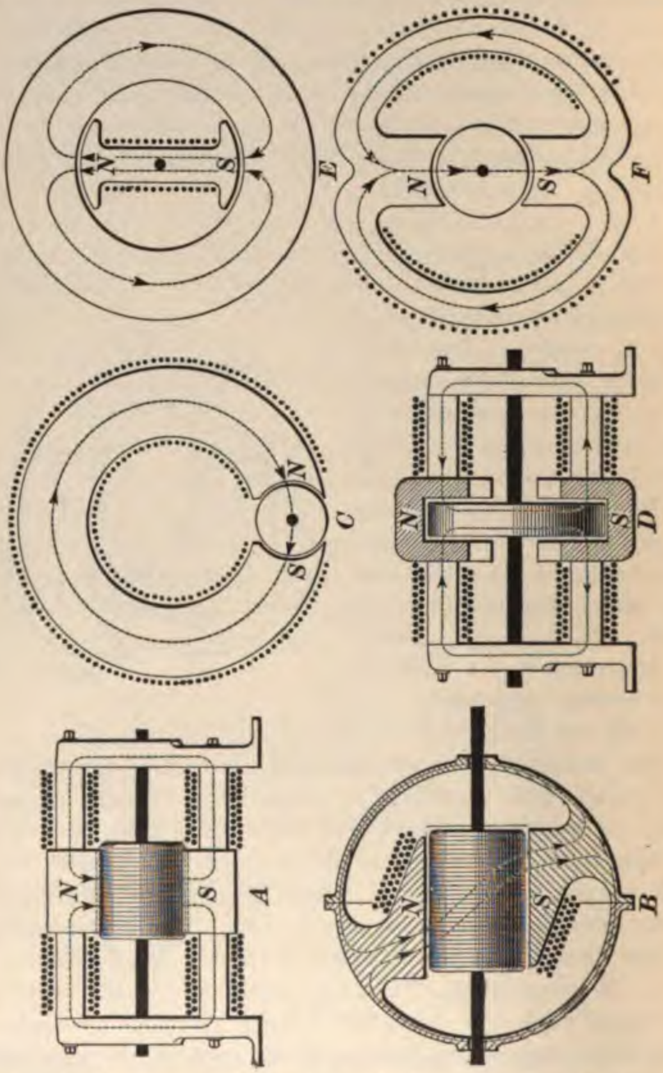


FIG. 44.

the shunt current being reenforced by the series current. When the dynamo is not loaded, that is, when no current is



flowing in the external circuit, and the armature is rotated at normal speed, the normal E. M. F. is generated in the armature due to the magnetic field produced by the shunt coils alone. Upon closing the external circuit, however, the difference of potential between the brushes *tends* to

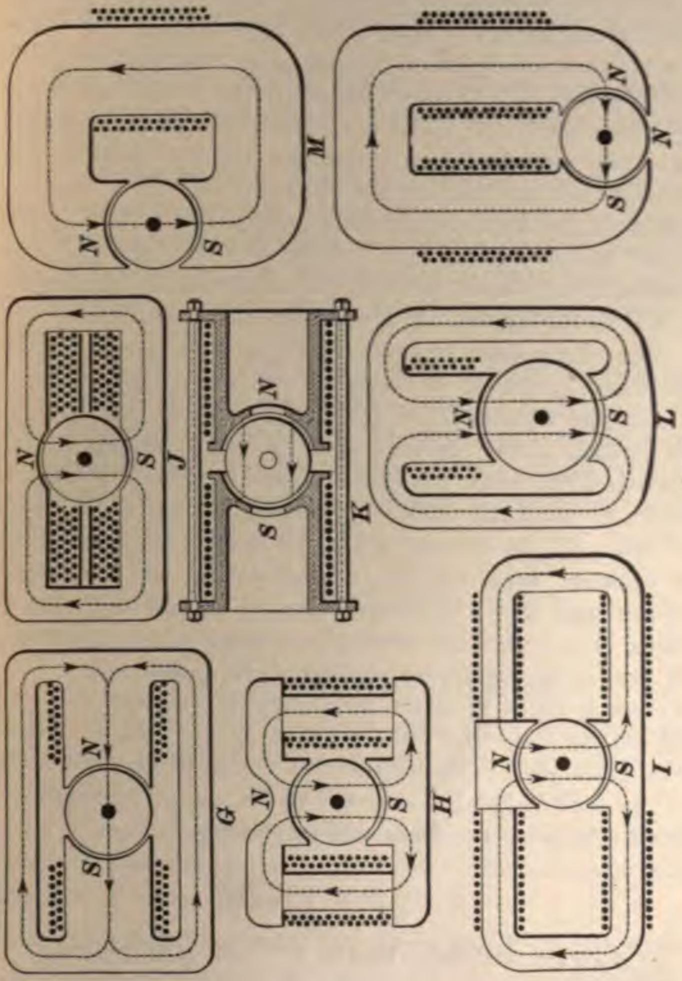


FIG. 45.

decrease, and would continue to decrease, as previously described in a simple shunt machine, if the series coils were neglected. The current circulating through these, however, reenforces the magnetizing force of the shunt coils, and immediately increases the number of lines of force in the field, which, in turn, raise the difference of potential between the brushes to normal. These actions are produced simultaneously, and, to all appearances, the difference of potential between the brushes remains normal for all changes of load in the external circuit. This method of regulating the E. M. F. of a dynamo is called **compounding.** The **terminals** of a dynamo are the binding posts to which the external circuit is connected; in a series, or compound, dynamo one terminal is attached to the outside end of the series coils, as $-T$ in Fig. 44, and the other terminal is connected directly to the brush, as represented by $+T$ in the figure. It is desirable in a great many cases to **over-compound** a dynamo, or, in other words, to wind a sufficient number of turns on the series coils so as to increase the difference of potential between the terminals of a dynamo above normal when the load increases. The expression **per cent. over-compound** means that the difference of potential between the terminals increases a given per cent. of the normal when the load is at a maximum. For example, supposing the normal voltage of a dynamo is 500 volts and it is 10% over-compound at full load; the difference of potential between the terminals of the machine at full load is, therefore, $500 + (500 \times .10) = 550$ volts.

In some cases it is an advantage to connect the shunt coils outside the series coils; that is, in Fig. 44, to connect the negative end of the shunt coil to the negative terminal instead of being connected to the negative brush $-B$. This connection is seldom used in practice.

FORMS OF BIPOLAR FIELD MAGNETS.

[illegible] types of field magnets for dynamos in [illegible] revolves between only one pair of poles [illegible]. It is customary to speak of such [illegible] dynamos, from the fact that only one pair of poles is presented to the armature. The broken lines and arrowheads in each of the separate cuts represent the paths of the lines of force which must pass lengthwise through the coils from the north pole to the south pole. The black dots indicate a cross-section through the wires which form the coils.

Field poles are distinguished as follows with respect to the coils producing them: (*a*) **salient poles**; (*b*) **consequent poles.**

In all cases where a single coil is used, or where, if two coils are used, they are wound so as to produce unlike poles at their free ends, the poles are called salient poles. When two coils are used and wound so as to make their adjacent poles similar, the resultant poles are called consequent poles.

Referring to Fig. 45, salient poles exist in fields *B*, *C*, *G*, *J*, *K*, *L*, *M*, *N*, and consequent poles in *A*, *D*, *E*, *F*, *H*, *I*. The adjacent coils in *A*, Fig. 45, have their adjacent poles at *N* and *S* similar. Were these poles opposite, the magnetic flux would circulate around the magnets without passing through the armature.

TYPES OF DYNAMOS.

44. Dynamos are divided into three general types, depending on the character of their currents. These three types are:

1. **Constant-potential dynamos,** in which the E. M. F. remains constant and the strength of current (continuous) changes with the load or external resistance.

2. **Constant-current dynamos,** in which the strength of current (continuous and pulsating) remains constant and the E. M. F. changes with the load.

3. **Alternating-current dynamos,** the current from which alternates or reverses direction with great rapidity

and whose E. M. F. is constant. In ordinary alternating-current dynamos, the reversals average generally either 7,200 or 16,000 per minute.

NOTE.—A dynamo which generates current for power purposes has been conventionally termed a *generator*, to distinguish it from a machine for lighting.

CONSTANT-POTENTIAL DYNAMOS AND GENERATORS.

45. The foregoing articles have demonstrated the principle and regulation of constant-potential dynamos, but only one form has been considered, namely, a dynamo in which a ring or drum armature is rotated between only one pair of poles from a U-shaped magnet. Theoretically, however, constant-potential dynamos can be built with one armature revolving between any number of pairs of poles, although in practice eight pairs of poles are seldom exceeded, except in machines for large output and slow speed. Machines having more than one pair of poles are called **multipolar dynamos.**

In multipolar dynamos the pole pieces and field cores are fastened into one magnetic yoke, more or less circular in shape, as shown in Fig. 46, which represents the magnetic circuits of a four-pole dynamo. A magnetizing coil is wound upon each field core, and the four coils are connected in series in such a manner that when a current circulates around the coil, it produces first a north pole and then a south pole. The lines of force from each field core divide into two magnetic circuits in

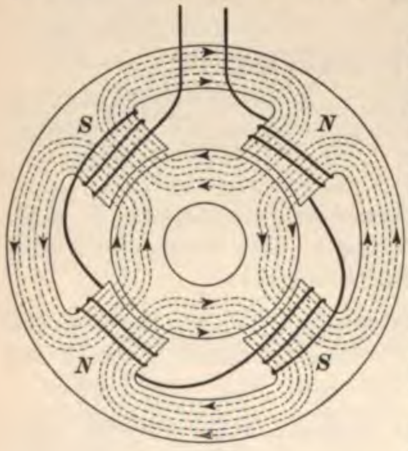


FIG. 46.

the yoke and armature, as represented in the diagram. Their density is practically uniform, however, where they pass from the north pole into the armature core, or from the armature core into the south pole. In nearly all multipolar dynamos this same principle of polarity is applied, that is, every *other* pole is of like polarity, and lines of force from each core divide into two magnetic circuits, in the armature and in the field yoke.

46. The process of generating an E. M. F. is similar to that in bipolar machines, but there are some points which should be understood. Consider first the case of a ring core with a closed-coil winding as shown in the diagram, Fig. 47. If the armature is rotated in the direction of the large arrow, the E. M. F. generated in the conductors in front of the south poles will tend to act downwards along the face of the pole, while that generated in front of the north pole will

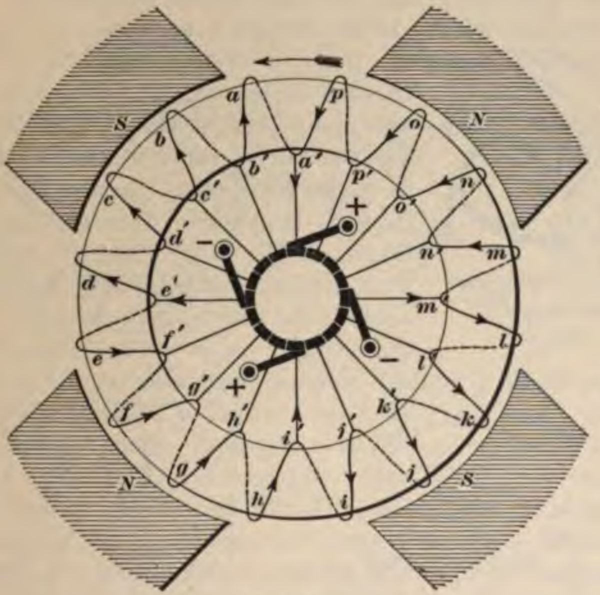


FIG. 47.

tend to act upwards. By tracing out, by aid of the small arrowheads on the conductors, the direction in which the E. M. F. acts, it will be seen that there are four points where the E. M. F. acts in opposite directions. The action of the electromotive forces is to meet at a' and i' and to divide at e' and m'. The segments connected to a' and i' have the same potential and form two *positive* neutral points of the commutator; the segments connected to e' and m' have the same potential and form two neutral points of the commutator. Hence, four brushes are necessary—two positive and two negative. The current is obtained from the armature by connecting the two positive brushes in parallel to one terminal of the external circuit and the two negative brushes to the other terminal, as shown in Fig. 48. The currents from the positive brushes unite to form the current in the external circuit and divide again between the negative brushes. The current in the armature is divided into four circuits in parallel instead of two, as in bipolar dynamos, and the maximum E. M. F. that is obtainable from the brushes is equal to that generated by the active conductors in one of the circuits only. For example, the difference of potential between the positive and negative brushes in Fig. 47, when no current is flowing, is equal to the E. M. F. generated in one-quarter of the outside wires on the core; or, in other words, the total E. M. F. of the armature is proportional to the number of outside wires connected in series between brushes of opposite polarity.

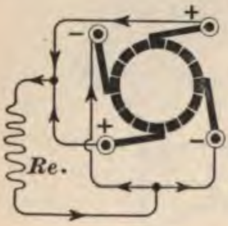


FIG. 48.

The current in a ring armature wound and connected in this manner, if placed in a field magnet of six poles, would divide into six circuits in parallel; if the armature is placed in a field magnet of eight poles, the current would divide into eight circuits in parallel, and so on. An armature winding of this character is called a **parallel,** or **multiple, winding,** since the current divides into as many circuits in parallel as there are poles in the field magnet.

47. It is possible, however, to connect and group the conductors in an armature for a multipolar dynamo so that

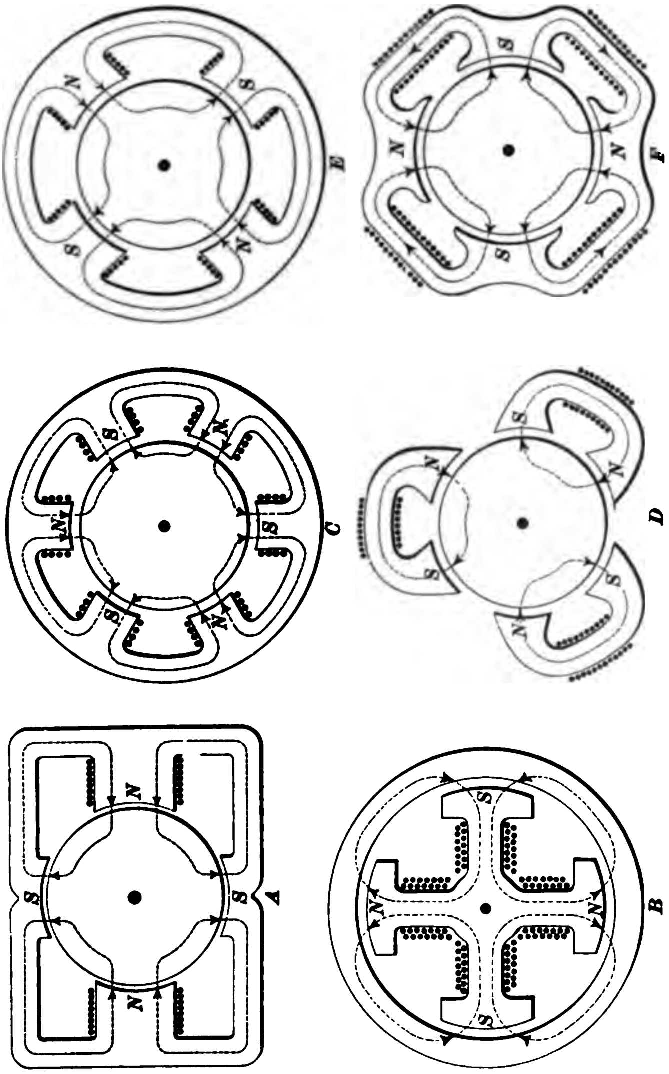


FIG. 49.

the current divides into two circuits only, making the number of active conductors in series equal to one-half the total

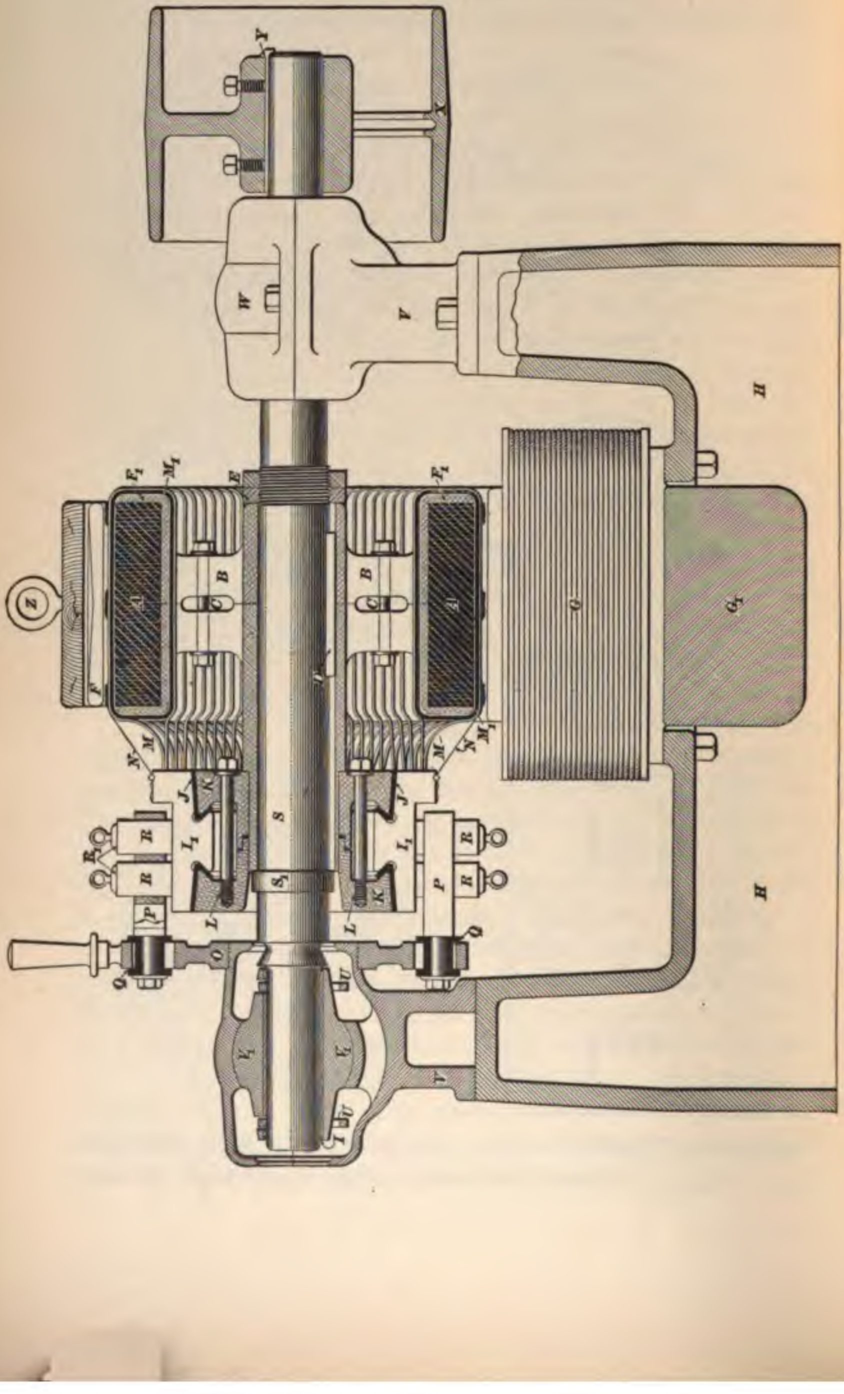


FIG. 50.

number of outside wires on the core. This armature winding is termed a *series winding*, since one-half of the total outside wires is the largest possible number that can be connected in series and produce a continuous current.

There are many different methods of connecting and winding armatures for generating a continuous current, the method used depending upon the character of the current and E. M. F. desired. Drum windings as well as ring windings are connected in a variety of ways for multipolar and bipolar dynamos, but the principle of commutation and generation of E. M. F. does not differ from that previously described; the E. M. F. is always proportional to the number of outside or active wires connected in series.

48. The regulation of multipolar dynamos for constant potential is accomplished by the changing of the strength of the magnetizing force, as in the bipolar machines. In a compound dynamo, the series coils are wound on each field core and all connected together in parallel or series, whichever is more expedient.

49. Types of Multipolar Field Magnets.—The various types of multipolar field magnets are shown in Fig. 49. Consequent and salient poles are used as in bipolar field magnets, but the type generally employed has salient poles alone, as in *C* and *E*. *A* embodies both consequent and salient poles. In *B* the field magnet is surrounded by the armature and is known as an *internal-pole* dynamo. The armature in all cases is that part of a dynamo in which the current is generated. Each type of field magnet in the above figure has its own special advantages, but all represent good design.

50. Mechanical Construction.—Heretofore, only the principles of a dynamo have been considered; its mechanical construction in detail depends upon the requirements of the machine and upon the originality and taste of the designer. A few general remarks, however, on the construction of the principal parts of the machine are necessary cotton or rubber tape; an electrical contact of two leads will short-circuit and burn out the intervening coil. It is sometimes the practice to use the armature conductors themselves for leads by looping the conductor and connecting the end of the loop to the commutator. This is bad practice, however, and, except for small dynamos, ought not to be followed. A large, solid copper wire is liable to become crystallized by the repeated vibration of the machine and will eventually give way.

53. Commutator.—Every maker of dynamos has a special design of commutator, but all embody the same general construction. Fig. 51 shows two enlarged views of a commutator such as is shown in place in Fig. 50. It will be noticed that the segments are broader on the outside of the commutator than near the center, thus providing for an equal thickness of insulation between all parts of adjacent bars. A portion a of each segment projects above the general level of the commutator surface, and is provided with a slot into which the armature leads are securely fastened by screws s, s, as shown at l. Sometimes the leads are soldered to the segments. The method of clamping and securely holding the segments is shown in the lower view. The commutator shell, it will be seen, consists of two rings $c\,c$ and $c_1\,c_1$, clamped together by bolts b, b. The notches n in the segments fit over corresponding projections on the rings, and as the bolts are tightened the segments are drawn firmly against the insulation which separates them. The commutator shell is usually made of brass, sometimes of cast iron. This shell is, of course, thoroughly insulated from the commutator segments. A key is fitted into the commutator shell and shaft to cause the commutator to turn with the shaft. The armature leads from the winding are soldered or screwed to ears or clips extending from each commutator bar, as shown by the cross-sectional view.

54. Brushes and Brush Holders.—In the cut of the machine in Fig. 50, the brushes shown are made of carbon and rub against the segments of the commutator radially, the pressure being regulated by a spring which is attached to a hammer pressing on top of the carbons. The carbons slide in slots in the brush holders, fitting snugly, with but little play or lost motion sideways. Both brush holders are provided with studs which pass through holes in the rocker-arm, each stud being insulated from the arm by insulating bushings, as shown in the cross-sectional view. The rocker-arm is fitted over the journal-box, and can be rocked or rotated to change the position of the brushes on the commutator as the position of the neutral points changes when

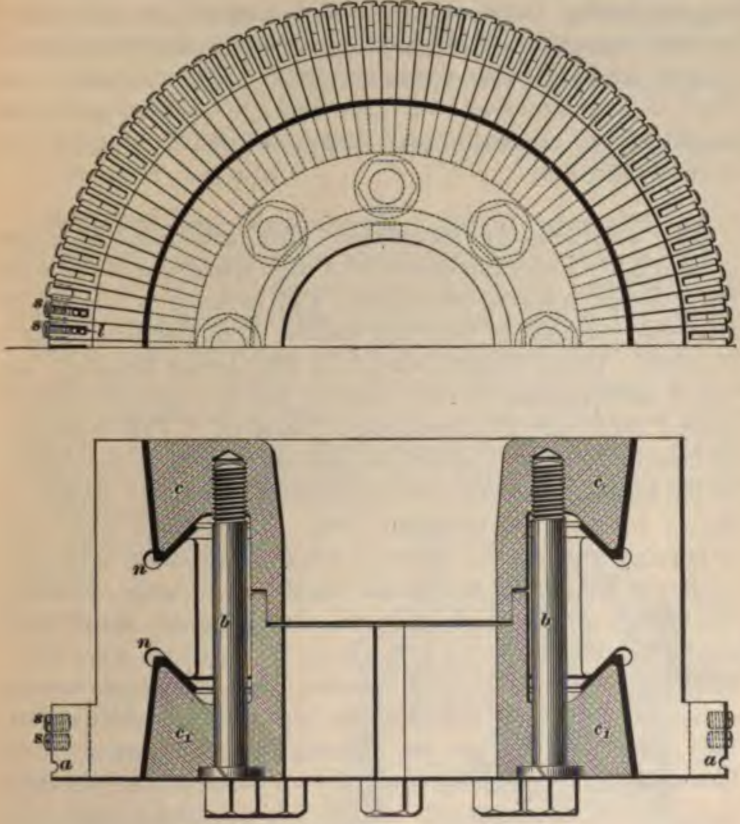


FIG. 51.

the load is varied. This action is usually accomplished by a handle attached to the rocker-arm; and a thumbscrew or set-screw is provided to hold the rocker-arm in position when properly adjusted. The current is taken from the brushes by a cable or flexible conductor connected to the brush holder, generally by the use of a small cable clip surrounding the stud. On some kinds of dynamos it is customary to use copper brushes; that is, brushes made either of copper leaves, strips, wires, or gauze. Such brushes are built in a great variety of ways, and on constant-potential machines are generally used where the E. M. F. does not exceed 125 volts.

55. Journals or Bearings.—The armatures of most dynamos are generally driven at a high speed compared with the average rotating machinery, and hence it is important that the journals or bearings should be of the best design possible. In the dynamo shown in Fig. 50 the bearings are called **self-alining** boxes; that is, the linings are allowed to find their own alinement with the shaft. This is accomplished by turning a spherical surface V_1 around the center of the lining and turning the cap and standard to match, as shown in the cross-sectional view. The linings l in such a bearing are usually made of some composition metal, as bronze or gun-metal, for small machines; on large machines the linings are made of cast iron covered on the inside with babbitt metal.

The best practice in lubricating high-speed journals in dynamos is to make the bearings *self-oiling* or *self-lubricating*; that is, to design the bearings with a reservoir of oil below the journal, using some device to carry the oil from the reservoirs to the top of the journal, from whence it flows around the journals and drops back into the reservoirs again. This method produces a constant circulation of oil around the journals and allows the oil to be used over and over again.

A good method of automatically oiling or lubricating [illegible] journals is shown in the cross-sectional view in

Fig. 50. Two slots are cut across the top of each lining, permitting two circular *oil rings U* to rest upon the journals of the shaft; the diameters of the rings are made large in comparison with the diameter of the shaft, and their lower parts dip into the reservoirs of oil. When the shaft is rotated, the friction between it and the inside of the oil rings causes the latter to revolve, thus carrying the oil which adheres to the bottom part of the rings to the top of the journal, where it finds its way between the linings and the shaft.

In general, any freely lubricated journals can be used in dynamos or generators.

56. Driving Mechanism.—The armatures of nearly all dynamos are driven in one of the following ways: (1) By using a flat belt passing over a pulley on the armature shaft. (2) By using several ropes, side by side, running in a grooved pulley. (3) By connecting the armature directly to the crank-shaft or shaft of the driving machine, which, in most cases, consists of a steam engine, steam turbine, or water-wheel. In any of the above methods, the driving mechanism should be amply capable of transmitting the total output of the dynamo with a suitable factor of safety.

57. A perspective view of the bipolar dynamo just described is shown in Fig. 52. In the figure the machine is represented as ready for operating, and is mounted upon sliding rails which are attached to the wooden *bedplate*. Two adjusting screws, one on each side of the

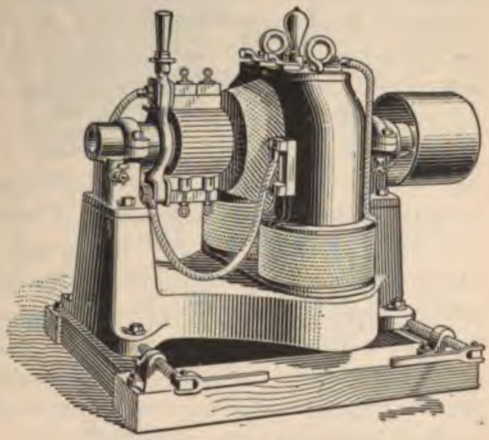


FIG. 52.

machine, are used to move the dynamo along the rails, thereby loosening or tightening the belt as the circumstances may require. The current passes from the brush holders through flexible copper cables to two terminals fastened to, but insulated from, the pole pieces; from the terminals the current passes through the series winding on the field or magnetizing coils, and thence to a small connection board on the top of the pole pieces. An incandescent lamp is connected between the main terminals of the connection board, and is used to indicate when the machine is generating its normal E. M. F. A lamp used for this purpose is usually called a **pilot lamp.**

58. A multipolar dynamo for developing a constant potential and ready for operating is shown in Fig. 53. In this machine the frame is made of two main castings; one consisting of the upper magnetic yoke and two pole pieces,

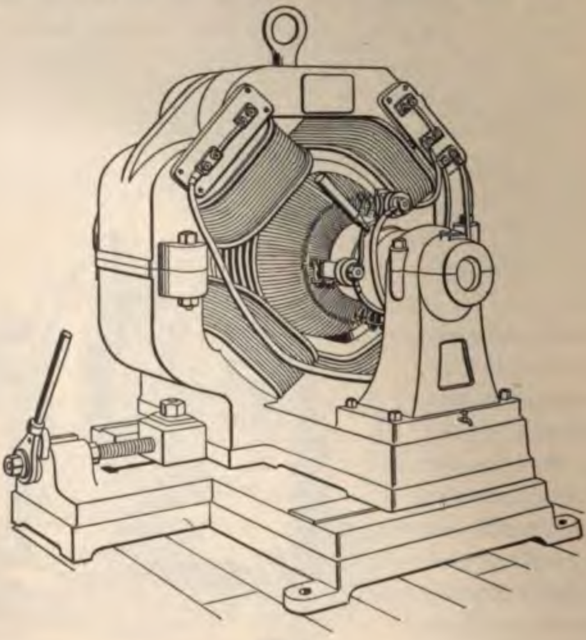


FIG. 53.

and the other consisting of the lower magnetic yoke and two pole pieces, from which project two extensions for supporting the pillow-blocks. The dynamo slides upon a cast-iron bedplate, and adjustment is made by a screw, as in the case of the bipolar dynamo.

The two dynamos previously described are illustrations taken from actual practice and embody some special features which are not found in other machines of the same character; they were selected, however, on account of their simplicity, to convey to the student a general idea of how electrical principles are combined with mechanical construction.

EFFICIENCY OF CONSTANT-POTENTIAL DYNAMOS.

59. As previously stated, a dynamo is a machine for converting or transforming mechanical into electrical energy. In any transformation of energy, the total amount of energy is constant; when energy which is manifested in one form disappears, the same quantity will always appear again in another form or in several other different forms. This action is exactly that which takes place in a dynamo. A certain amount of mechanical energy is delivered to the armature shaft of the dynamo by a belt or some other transmitting device; a large portion of the energy is converted into electrical energy in the armature conductors and is transmitted to the external circuit, while the rest of the energy, usually the smaller portion, is converted directly or indirectly into heat energy in the different parts of the dynamo itself. The amount of energy delivered to the armature shaft is always equal to the energy appearing in the external circuit from the brushes, plus the energy converted into heat in the dynamo itself.

In a dynamo the mechanical energy delivered to the armature shaft is usually called the **input**; the electrical energy appearing in the external circuit from the brushes is called the **output**; and the energy converted into heat directly or

From 15,000 to 100,000 watts output inclusive, about 90% efficiency.

From 150,000 watts output and upwards, from 91 to 93% efficiency.

The method of actually testing a dynamo to find its efficiency and losses is beyond the scope of this section; the above, however, will serve as a guide to the student when computing the necessary power required to drive dynamos of different capacities or outputs.

62. When the output of a dynamo and its corresponding efficiency are given, the input necessary may be found by the formula

$$I = \frac{100 \times O}{\mathrm{E}}. \qquad (4.)$$

That is, *the input necessary to drive a dynamo, when its output and efficiency at that output are given, is obtained by dividing the output by the per cent. efficiency and multiplying the quotient by 100.*

EXAMPLE 1.—The efficiency of a constant-potential dynamo is found to be 85% when giving an output of 6,341 watts; find the input in horsepower necessary to drive its armature shaft under these conditions.

SOLUTION.—By formula **4**, the input necessary $I = \frac{100 \times 6{,}341}{85}$ = 7,460 watts. The equivalent of 7,460 watts in horsepower is $\frac{7{,}460}{746}$ = 10 horsepower, which is the power required to drive the armature shaft of the dynamo under the stated conditions. Ans.

When the input of a dynamo and its corresponding efficiency are given, the output may be found by the formula

$$O = \frac{I\,\mathrm{E}}{100}. \qquad (5.)$$

That is, *the output of a dynamo, of which the input and the efficiency at that input are given, is obtained by multiplying the input by the per cent. efficiency and dividing by 100.*

EXAMPLE 2.—An input of 35 horsepower is delivered to the shaft of a dynamo; if its efficiency at that input is 89.5%, find its output in watts.

SOLUTION.—The equivalent of 35 horsepower is $35 \times 746 = 26,110$ watts. By formula **5**, the output of the dynamo under these conditions,

$$O = \frac{26,110 \times 89.5}{100} = 23,368.45 \text{ watts. Ans.}$$

63. The total loss of power in a dynamo can be separated into smaller losses, depending upon the manner in which the loss is produced and the part of the dynamo in which it occurs. In ordinary cases, all the losses will come under one or more of the following heads:

1. Mechanical-friction loss.
2. Core loss.
3. Field loss.
4. Armature loss.

64. Friction Losses.—The larger part of the loss due to mechanical friction takes place between the bearings and journals. The brushes rubbing on the commutator produce some friction and consequent loss, but the amount is small, unless carbon brushes, under heavy pressure, are used. The per cent. of power lost in mechanical friction necessarily depends upon the construction and condition of the bearings and journals, upon the size of the machine, and, to some extent, on the method of driving the armature shaft. Under ordinary conditions, the loss in mechanical friction should not exceed 5% of the input of dynamos from 1,500 up to about 10,000 watts output, and 3% of the input of dynamos from 15,000 to 100,000 watts output. For example, suppose that a dynamo has an efficiency of 88% at its rated output of 22,000 watts, and a test shows that 2.5% of the input is lost in mechanical friction. The total loss in the machine is $100 - 88 = 12\%$, of which 2.5% is lost in friction; the remaining 9.5% loss is due to other causes. The total input to the machine, from formula **4**, is $\frac{22000}{88} \times 100 = 25,000$ watts; hence, the power lost in friction is $\frac{25,000 \times 2.5}{100} = 625$ watts.

65. Core Losses.—The core loss is the energy converted into heat in the iron disks of the armature core when of watts (W) required to excite the field magnets $= C^2 r$ $= 100^2 \times .1 = 100 \times 100 \times .1 = 1{,}000$ watts.

67. In a shunt dynamo which generates a nearly constant potential for limited strengths of current in the armature, the field coils usually consist of a large number of turns of fine wire, offering a high resistance compared with the field coils of a series dynamo. The two terminals or ends of the shunt field coils are connected to the positive and negative brushes, respectively, of the dynamo in parallel with the external circuit, thereby allowing the full potential of the dynamo to act against the resistance of the coils. Then, from Ohm's law, the current in the shunt coil is equal to the electromotive force of the brushes divided by the resistance of the coils. Let E_e represent the difference of potential between the brushes of the dynamo when running at normal speed and fully excited, let r_s represent the resistance of the shunt coils, and C_s represent the current in the shunt coils. Then, from Ohm's law, the current in the shunt coils is given by the formula $C_s = \frac{E_e}{r_s}$. For example, suppose that a shunt dynamo, when running at a constant speed, generates a constant difference of potential of 110 volts, and the resistance of the magnetizing coils from the positive connection to the negative connection is 55 ohms; or $E_e = 110$ volts and $r_s = 55$ ohms. Then, the current in the shunt coils would be given by substituting these values in the above formula, or $C_s = \frac{E_e}{r_s} = \frac{110}{55} = 2$ amperes.

This gives the strength of current in the shunt coils, but does not indicate the amount of power required to constantly excite the field magnets. The power in watts is $W = CE$; that is, it is equal to the current in amperes flowing through the shunt coils multiplied by the difference of potential in volts between the terminals of the shunt coils. We have found in this case that the current $C = 2$ amperes and the E. M. F. $E = 110$ volts; then, $W = 2 \times 110 = 220$ watts, which represents the power required to excite the field magnets.

All other conditions being similar, the same number of watts will be dissipated in a shunt field coil as in a series coil, provided an equal amount of magnetizing force is produced in the two cases.

68. In a compound-wound dynamo, the field loss consists of two losses, one in the series coil and the other in the shunt coil. The loss in the series coil depends upon the strength of current flowing from the dynamo, as in the case of a simple series dynamo, while the loss in the shunt coil is constant, irrespective of the load on the machine; provided, of course, the dynamo generates a constant electromotive force for all loads. This can readily be understood from the following example: A dynamo is compounded to generate 220 volts between its terminals for all loads up to its rated capacity; that is, when the current from the armature becomes stronger and the difference of potential between the terminals tends to fall, the current in passing through the series coil strengthens the field magnets sufficiently to keep a difference of exactly 220 volts between the terminals of the dynamo. Assume the resistance of the shunt coil to be 275 ohms and that of the series coil to be .055 ohm. At a rated output of 4,400 watts, the current flowing through the series coil and into the external circuit is $\frac{4400}{220} = 20$ amperes (assuming the connections are made for a *short shunt*). At all loads the current in the shunt coil is $C_s = \frac{E_e}{r_s} = \frac{220}{275} = .8$ ampere, and the loss of power in the shunt coil is $W_s = E_e \times C_s = 220 \times .8 = 176$ watts; even when the external circuit is open the loss in the shunt coil remains constant, or 176 watts in this particular case. The loss in the series coil, however, varies directly with the square of the current passing through it. In this example, the loss in the series coil is $W = C^2 \times r = 20^2 \times .055 = 22$ watts; at half load, or 10 amperes, the loss is $W = 10^2 \times .055 = 5.5$ watts, etc.; at no load there is no current in the series coil, and, consequently, no loss. The total field loss in a compound dynamo is the sum of the losses in the series and shunt coils. For instance, in this example, the total field loss at full load is 198 watts; at half load, 181.5 watts, and at no load, 176 watts.

69. The amount of power lost or dissipated in the field coils of a dynamo depends (1) upon the capacity of the dynamo, (2) upon its design, and (3) upon the amount of copper used in the coils. In the last condition it is obvious that in order to produce a certain number of *ampere-turns*, the current in amperes required could be made exceedingly small by using a large number of turns of copper wire, thereby reducing the electrical loss. A limit is reached, however, where it is not economical from a commercial standpoint to increase the amount of copper in order to save in electrical loss.

The per cent. loss in the field coils of dynamos varies from about 10% of the input to dynamos having an output of about 1,000 watts to as low as 1.5% to 2% of the input to dynamos having an output of 100,000 watts and upwards. For example, suppose that the input to a dynamo from an engine was 100 horsepower and the loss in the field coils was 2.5%. Under these conditions, how many watts are lost or dissipated in the field coils? Changing the input from horsepower to watts gives $100 \times 746 = 74,600$ watts, since 1 horsepower is equivalent to 746 watts. Hence, the number of watts lost in the field coils is $74,600 \times .025 = 1,865$ watts.

70. Armature Losses.—The principal armature loss is that produced by the current in flowing against the internal resistance of the armature, that is, the resistance of the armature *conductors*. The *core losses* previously described could also be classed as part of the armature losses, but it is usual to consider them apart. The armature loss proper is usually termed the **copper**, or **wire, loss,** since it is due to the resistance of the armature conductors, which are composed of copper wire or bars. The internal resistance of an armature is an exceedingly variable quantity, depending upon the form, construction, size, number of conductors, size of conductors, etc. In constant-potential dynamos, generally speaking, the internal resistance of the armature must necessarily be comparatively small, since it determines the maximum strength of current that can be obtained from the dynamo, as will be seen subsequently.

The armature loss depends upon the amount of internal resistance and upon the strength of current flowing through the armature conductors. In a given armature the internal resistance remains constant at equal temperatures, while the strength of current varies with the load upon the dynamo at that particular moment; in other words, this loss only occurs when there is a current flowing through the armature—the stronger the current, the greater is the loss, and vice versa. As previously shown, in all cases where an electric current flows against the resistance of a conductor, the loss of power in watts is equal to the resistance of the conductor in ohms multiplied by the square of the current in amperes; hence, in an armature the number of watts lost in the armature conductors is equal to the square of the current in amperes flowing through the armature multiplied by the internal resistance in ohms of the armature from the positive to the negative brush. If C represents the total current in amperes flowing through the armature and r_i the internal resistance in ohms from the positive to the negative brush, then $W_i = C^2 r_i$, where W_i is the number of watts lost in the armature conductors. From this fact, this armature loss is also designated as the **C^2 r loss.** For example, suppose that the internal resistance of an armature from brush to brush is .125 ohm, and a total current of 40 amperes is flowing through the armature. Determine the number of watts lost in the armature. Let $C = 40$ amperes and $r_i = .125$ ohm; then, $W_i = C^2 r_i = 40^2 \times .125 = 200$ watts.

The per cent. loss in armatures of constant-potential dynamos varies from about 12% of the input to dynamos having a rated capacity of about 1,000 watts to as low as 1.5% to 2% of the input to dynamos having a rated capacity of about 100,000 watts and upwards. For example, suppose that a dynamo was working under a load which required 50 horsepower to run it, and, at this rating, the armature

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[illegible] loss be assumed as 3% of the input; determine the number of watts dissipated or lost in the armature conductors. Changing the input from horsepower to watts gives 50 × 746 = 37,300 watts, since 746 watts are equal to 1 horsepower. The armature [illegible] loss is therefore 3% of the input, or 37,300 × .03 = 1,119 watts.

71. Other Losses.—Aside from the four principal losses mentioned, other small losses occur in some machines when the armature is revolving. If large conductors are used in the winding of the armatures, a difference of potential [illegible] generated between the edges of the conductors [illegible] a manner as to give rise to small eddy or [illegible] currents in the conductors themselves, and which do [illegible] external circuit and are useless. In some [illegible] currents dissipate considerable energy and [illegible] when the machine is not loaded; [illegible] dynamos they are too small to be considered.

[illegible] which the conductors are wound in [illegible] the teeth between the slots have [illegible] of the lines of force where [illegible] This movement causes [illegible] generated in the pole pieces, [illegible] amount of energy. These [illegible] are sometimes termed Foucault currents, [illegible] the man who first recog[illegible] prevent these Foucault [illegible] having toothed arma[illegible] local currents may [illegible] on account of bad design, but it is [illegible] treat specifically upon such losses as are common to all dynamos and impossible to eliminate.

72. From the four previous [illegible] the following sum[illegible] a help to establish the rules of efficiency and

Input = the power driving the dynamo, which is derived from some outside agency.

Output = input minus the total losses.

Total losses = the sum of the friction, core, field, armature, and other losses.

Per cent. efficiency $= \frac{\text{input minus total losses}}{\text{input}} \times 100$, or $\frac{\text{output}}{\text{input}} \times 100$.

Per cent. loss in friction $= \frac{\text{friction losses}}{\text{input}} \times 100$.

Per cent. loss in core $= \frac{\text{core losses}}{\text{input}} \times 100$.

Per cent. loss in field $= \frac{\text{field losses}}{\text{input}} \times 100$.

Per cent. loss in armature $= \frac{\text{armature losses}}{\text{input}} \times 100$.

THE OUTPUT OF CONSTANT-POTENTIAL DYNAMOS.

73. If a dynamo is so constructed as to give a constant potential at any load, it is evident that the current flowing is inversely proportional to the resistance of the external circuit; that is, if the external resistance is reduced, the amount of current will be correspondingly increased. There is a limit, however, to the amount of current that any given machine can give out, depending on one (or both) of two factors; namely, the **heating** and the **sparking**.

The heat that is being continually generated in the armature and field coils of a dynamo when working under load, due both to the $C^2 r$ *loss* and the *core loss*, is given off from the surface of the armature and of the whole machine to the surrounding air. This giving off of heat can only occur when the dynamo is hotter than the air, for if two bodies are equally hot, one cannot give any heat to the other. Conversely, the greater the difference in temperature between two bodies, such as a dynamo armature and the surrounding air, the more heat will be given from the hot body to the cool.

74. When a dynamo is first started, it is at about the same temperature as the air, so that when the conductors in the armature begin to generate heat, this heat cannot pass off to the air, but instead it raises the temperature of the armature, until it is enough hotter than the surrounding air to cause all the heat which is being generated to be given off.

If the amount of heat generated is practically constant, as will be the case if the load remains constant, the temperature of the armature will also remain constant, because the heat is given off as fast as generated; and if the load is increased so as to increase the amount of heat generated, the temperature will again rise until the armature is enough hotter than the air to give off all this increased amount of heat.

It is evident, then, that when other conditions remain the same, the greater the load on a dynamo armature, that is, the more current it gives, the hotter it will get.

Now, at a certain temperature, the materials used in insulating the conductors of the armature, such as cotton, silk, shellac, paper, etc., will become ***carbonized***, that is, charred, or otherwise rendered useless as insulating material. For a short time these materials will withstand a temperature considerably above the boiling point of water (212° F.), but it has been found that if they are *continually* subjected to a temperature greater than about 180° F., they will gradually become carbonized; hence, as armatures are expected to last several years, they should never be subjected to a continual temperature greater than about 170° F. Consequently, the amount of current which will cause a dynamo armature to heat to about 170° F. is the limiting amount which that armature can *safely* give.

75. As an armature must be a certain number of degrees hotter than the air in order to give off the heat generated, it is evident that if the air itself were originally of a high temperature, the armature would actually have a higher *temperature* when giving off a certain amount of heat than if the air were cooler; that is, for a certain amount of heat generated, the temperature of the armature will rise to a certain number of degrees *above the temperature of the air.* The average temperature of the air in places where dynamos are installed is often as high as 90° F., so the allowable rise in temperature of the armature above that of the air is about 170 − 90 = 80° F., and dynamos are usually rated according to this rise in temperature.

As *still* air is a very poor conductor of heat, most of the heat given off to it is carried away by the motion of the air; this motion is partly due to the air-currents set up by the rise of the heated air and the flowing in of the cooler air to take its place, but mainly to the air-currents set up by the motion of the armature itself. This latter effect is usually greater in ring than drum armatures, due to the more open construction of the former and to the *fan* action of the spider arms.

The heat generated in the field coils is disposed of in the same way as that of the armature; that is, it is given off to the surrounding air. The rise in temperature of the field coils is subject to the same limitations as the rise of the armature; i. e., it is usually limited to about 80° F. above the temperature of the air.

76. By the *sparking* of a dynamo is meant the sparks which appear at the brushes, due to the *reversal of the current in the armature coils.* If the commutator is out of true or has one segment higher or lower than the others, or from other similar causes, there will be flashes or sparks at the brushes; but these are merely *mechanical* faults which can be easily remedied, and this is not what is meant by *sparking.* Referring to Fig. 28, it will be seen that in the armature coil $a'pp'$, when in the position shown, the general direction of the current is from right to left; but as soon as it moves into the position occupied by coil $b' a a'$, the general direction of the current is from left to right. Between these two positions the direction of the current must have been reversed, and this occurs during the time that the brush $+B$ is resting on *both* the commutator segments which are connected to this coil ($a' p p'$).

Now, it has been shown that if the amount of current in a coil is suddenly increased or decreased, the *self-induction* of the coil tends to set up an E. M. F. in the coil which *opposes* the change in the strength of the current. Hence, when the current is reversed in the armature coil as it passes from one side of the brush to the other, the self-induction of the coil tends to prevent this reversal, so that when one of the commutator bars to which the coil is connected passes out from under the brush, the current flowing from the side of the armature into which the coil is entering (the left side in Fig. 28) in trying to pass through this coil is opposed by the E. M. F. of self-induction of the coil. Instead of passing through the coil, then, the current jumps from the commutator bar through the air to the end of the brush, making a spark. The same action takes place at each point of commutation.

In order to prevent this sparking, which burns the commutator bars and the brushes, the brushes are shifted forwards ahead of the actual neutral point, until at the same instant that the current in a coil is reversed the coil is moving in the edge of the magnetic field that spreads out from the pole pieces, which generates in the coil an E. M. F. that is *opposite in direction to the E. M. F. of self-induction.* The consequence of this is that the E. M. F. of self-induction is diminished, which decreases the sparking. If the brushes are shifted to just the right position, the E. M. F. generated in the coil by the magnetic field will just equal the E. M. F. of self-induction, and there will be no opposition to the reversal of the current, hence no sparking. This is seldom actually done, as the E. M. F. of self-induction changes with every change in the strength of the current; but the effect of a certain amount of shifting of the brushes will usually so nearly counterbalance the E. M. F. of self-induction that the sparking will be slight at different loads.

77. It has been shown that the current in the armature winding reacts upon the magnetic field, forcing the actual neutral point ahead (in the direction of rotation). Now, if the brushes are moved ahead of this neutral point to avoid sparking, the effect is to move the consequent poles (due to the current circulating in the armature winding) also ahead, which shifts the neutral point still farther ahead, which requires a further slight shifting of the brushes. As long as the field due to the magnetizing coils is much stronger than the reactive effect of the armature, this action is slight, so that only a slight shifting of the brushes is necessary for practically sparkless operation. As the current in the armature increases, its reactive effect grows stronger, and a movement of the brushes is followed by a considerable movement of the neutral plane. Indeed, if the current in the armature is strong enough, the brushes may be shifted more than half way around the commutator without coming to the sparkless position. There is, therefore, a limit to the amount of current which can be taken from an armature (aside from its heating limit), which is reached when any further amount of shifting of the brushes will not afford sparkless commutation.

This amount of shifting is generally confined to the space between the tips of the pole pieces; that is, the brushes may be shifted until the coil short-circuited by a brush is at or just under the tip of a pole piece.

In dynamos of good design, the heating limit and sparking limit are reached with about the same current; that is, a current which will raise the temperature of the armature above that of the air by the amount decided upon as a limit will also necessitate the brushes being shifted to the maximum allowable extent. In some modern railway generators, the output is limited more by the heating than by the sparking. Such machines may stand a 50 per cent. overload without excessive sparking. Moreover, by careful designing and the use of carbon brushes, sparkless commutation can be obtained without shifting the brushes forwards as the load comes on. In fact, where the load fluctuates rapidly, it would be practically impossible to shift the brushes and for such work a fixed point of commutation is almost essential.

78. It is evident that while a brush is resting on two commutator bars at the same time, the coil connected between these two bars is *short-circuited*, the current from the two sides of the armature passing into the brush, one-half through each of the two commutator bars, without passing through the short-circuited coil. The resistance which the current meets in passing from the bars into the brush is evidently the *contact resistance* of the surfaces which are in contact. When the brush rests equally on both commutator bars, the contact resistance opposed to each half of the current is the same; but as one of the bars moves out from under the brush and the other moves farther under it, the contact resistance is altered, and there is more opposition to the passage of one-half the current into the brush than there is to the other. Now, with *metallic* brushes, which have a very low contact resistance if properly made, this difference is not enough to give any appreciable opposition to the current until the commutator bar is actually leaving the brush; hence, the current is *suddenly* forced to pass through the coil which has just been short-circuited. With *carbon* brushes the contact resistance is much greater than with metallic brushes; when the two bars are equally under the brush, this contact resistance is opposed equally to the current from each half of the armature, but as the one commutator bar begins to move from this position, the resistance opposing the current which is passing from that bar into the brush is great enough to force a part of the current around through the short-circuited coil and into the brush through the *other* commutator bar, in spite of the E. M. F. of self-induction of the coil.

From this it follows that, with metallic brushes, much more care must be taken than with carbon brushes, to place the short-circuited coil in a field which will generate an E. M. F. equal to the E. M. F. of self-induction, since the absence of sparking depends mainly on this point. With carbon brushes the absence of sparking depends both on generating an E. M. F. in the coil and on the contact resistance of the brush. On account of the increased resistance of contact, carbon brushes require less shifting for variations in load than do metallic brushes, and are generally used on machines where the variations in load are so frequent and extensive that a great deal of time would be spent in shifting the brushes, if this had to be done for every change in the load.

79. If the brushes are shifted so far forwards that the E. M. F. generated in the short-circuited coil is *greater* than the E. M. F. of self-induction, not only will the latter be neutralized, but a current will be sent around the coil through the commutator bars and the brush which short-circuits the coil. If this current is greater than the current which one-half of the armature is supplying to the external circuit, it is evident that when the short-circuited coil moves over and becomes a part of that half of the armature, its current will be *reduced;* this reduction is opposed by the self-induction of the coil, as before, and sparking results. Since the circuit of the short-circuited coil is partly through the brush and its contact with the commutator bars, it is evident that with metallic brushes of low resistance the liability of the current in this coil becoming excessive is greater than with carbon brushes of (comparatively) high resistance. For the reason, therefore, that they are of higher resistance, carbon brushes will spark less than metallic brushes under the same conditions.

DIRECT-CURRENT MOTORS.

80. It has already been explained that a conductor carrying current at right angles to a magnetic field will move across the field. This is, in brief, the principle on which an electric motor operates. If we take an ordinary direct-current dynamo and, instead of driving it from some outside source of power and making it generate an E. M. F., we supply it with current from some outside source, say another dynamo, the machine will run as a motor and deliver power at its pulley. A direct-current motor, then, is the same as a dynamo, so far as its construction goes. The difference between a dynamo and a motor has more to do with the way in which the machines are used than with any radical difference in their construction. At one time it was thought that motors should be constructed different from dynamos, but it is now known that the machine that makes a good dynamo will nearly always make a good motor. Of course, motors often differ considerably from dynamos in their mechanical details, because motors must often be adapted to special work for which the ordinary mechanical construction of a dynamo would be unsuitable. For example, railway motors must stand all sorts of abuse, and hence must be enclosed as much as possible. As regards their electrical features, however, direct-current dynamos and motors are the same; when a machine is used as a dynamo, it is supplied with power and it converts this power into electrical energy; when it is used as a motor, it is supplied with power in the shape of an electric current, the reaction between the current in the armature conductors and the magnetic field set up by the field magnets forces the armature to revolve, and the machine, therefore, converts the electrical energy supplied at the brushes into mechanical energy delivered at the pulley.

CLASSES OF MOTORS.

81. Motors, like dynamos, may be divided into several classes according to the method used for exciting their field magnets. We may then class them as *series-wound*, *shunt-wound*, *compound-wound*. The last class may be subdivided into *differentially wound* and *accumulatively wound*, according as the series field coils are connected so as to *oppose* or *aid* the shunt coils. Nearly all motors in common use are operated at constant potential, and we will confine our remarks here to motors that are so operated.

82. Shunt-Wound Motors.—Shunt-wound motors are very extensively used for stationary work for operating all classes of machinery where a fairly constant speed is required. A constant-potential shunt-wound motor is the same as regards construction as the corresponding shunt-wound dynamo. When supplied with a constant pressure, it will run at nearly constant speed, no matter what may be the load, up to the limit of the machine. The speed drops off slightly with an increase of load, but the falling off is slight if the motor is well designed. A shunt-wound motor will give a good starting effort if the field is fully excited before the current is allowed to pass through the armature. For stationary work, the shunt-wound motor is the one most largely used.

83. Series-Wound Motors.—These motors are used most largely for work when a wide variation in speed is desired, where the motor is to be started and stopped frequently, and where a strong starting effort is needed. For these reasons they are used on street railways and for traction work generally, for hoists, electric cranes, and in some cases for pumps and similar machinery. Thousands of series-wound, direct-current motors are in use for operating street cars alone. Since the field is in series with the armature, the strength of the field depends on the current flowing through the motor. If at starting a large current is allowed to flow, the field is made very strong, and as the current in the armature is also very large, a powerful starting effort is the result. This is a valuable feature if the motor is to be used for traction or hoisting work. The speed of a constant-potential series motor varies widely if the load on it is varied, because every change in load produces a corresponding change in the field strength. If the load is thrown off entirely, the motor will race, and may reach a speed high enough to injure itself.

84. Compound-Wound Motors.—These motors are not largely used, compared with the other two classes. They are used mostly for special purposes, such as operating printing presses, looms, etc. When a speed that is very nearly constant under all loads is required, the differentially wound motor is used. When a motor is required that will have a fairly good starting effort combined with the property of approximately constant speed, the accumulatively wound motor is employed. In this motor the series coils aid the shunt coils, and when starting, the heavy current through the series coils strengthens the field, and thus gives a strong starting effort, or *torque*, as it is called.

OPERATION OF DYNAMOS AND MOTORS.

INSTALLATION.

1. Location.—The location of a large dynamo or motor is a matter generally determined by local surroundings; that is, the position of the dynamo depends on where its engine may be, and the disposition of the motor depends on what it is to drive and where it is located. Assuming, however, that the conditions are such that the selection of a site for the dynamo or motor is not hampered by other considerations than that the machine shall be put in a place best adapted to itself, the following points should be kept in mind: It should be kept in a clean, dry, cool place, out of reach of drippings from steam and water pipes, and protected from dropping of water due to the condensation that sometimes takes place on an iron roof. The machine should preferably be placed where there can be a draft of air across it from windows or doors on opposite sides, and in such cases, if it is located on the ground floor, there should be ample means for sprinkling the street in the vicinity to keep down the clouds of dust that are otherwise sure to be present in dry weather. This precaution will permit a free circulation of air when it is most needed—in the hot summer months.

The space surrounding the machine should be clean and free from all obstructions. Where the machine is controlled

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from a switchboard, a man should be able to go from one to the other without going through a belt or past a number of obstructions. Dust from the street is injurious to the commutator, bearings, and general insulation of electrical machines, but dust from a coal pile or any kind of grinding or turning machine is even more so; therefore, the engine and dynamo rooms should be protected from the dust incidental to coal handling, and no emery wheels, grinders, speed lathes, etc. should be allowed in the room. Where motors are installed in rolling mills, forge rooms, carbon works, or places where a great deal of power grinding or finishing is done, the motor should be of an enclosed type, its bearings should be protected, just as those of a grinder are, and the machine should be properly caged.

2. **Foundations.**—Every machine of 25 horsepower, or more, should be provided with a substantial foundation, and this foundation should, if possible, be independent of the floor and walls of the building in which it is installed, to avoid communicating to them the very disagreeable vibration incidental to the running of the machinery. Where there are several machines to be installed, the idea is best carried out by having the whole floor space subconcreted and capped with a layer of cement or a wood floor. Where a single machine is to be installed, it is sufficient to limit the foundation to a little more than its floor area. In any case, solid brickwork is the best foundation, but where its use is impracticable, a substantial wooden frame construction can be used. Even where the concrete or brick foundation is used, it is customary to cap this with a hardwood frame, served with a high-grade insulating compound of some sort; the layer of wood serves not only to insulate the metal frame of the machine from the ground, but it acts as a cushion to take up the blows and vibration. The insulation feature must not be defeated by having the bolts that secure the wood frame to the masonry come in contact with those that secure the metal frame of the machine to the wood.

No rule in regard to the depth of the foundation can be given to cover all cases, as the subsoil is so different in different places. In one section, bed rock will be found a few feet from the surface, while in another section of the country it will be necessary to drive piles to support the foundations for the heavier machines. Fig. 1 shows a style of foundation very much used; the foundation proper is made of brick laid with 1 part of the best cement to 2 parts of good, sharp sand. The surplus of excavation is filled in with a mixture of broken stone and cement, which is capped to a surface with pure cement. The masonry is built around the anchor bolts.

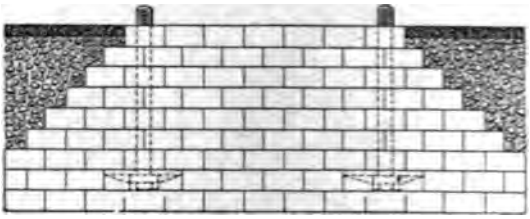

FIG. 1.

Wherever the machine is to be belt-driven, means should be provided for tightening or slacking the belt. On most machines this is usually accomplished by screws or by mounting the machine on rails or on a subbase and moving the machine by means of a ratchet lever and screw. As an example of this we may take the machine shown in Fig. 2. The foundation should in every case be so disposed that the distance between the driving and driven centers will allow one side of the belt to run looser than the other. This distance should be at least four times the diameter of the larger pulley.

3. Erection.—Small machines are, as a rule, shipped complete and ready to run, so that there is nothing to do but to put them in place, put the pulley on, and line them up. Large machines cannot be shipped with safety in an assembled condition, and some are so large that they could not be gotten through the door of a closed car; so they are dismounted and the parts marked and packed in separate parcels. It then falls upon the roadman or the purchaser to assemble them at their destination. This work should not be undertaken by one not familiar with such work, and even an expert should not be above consulting the blueprints and the marks on the parts.

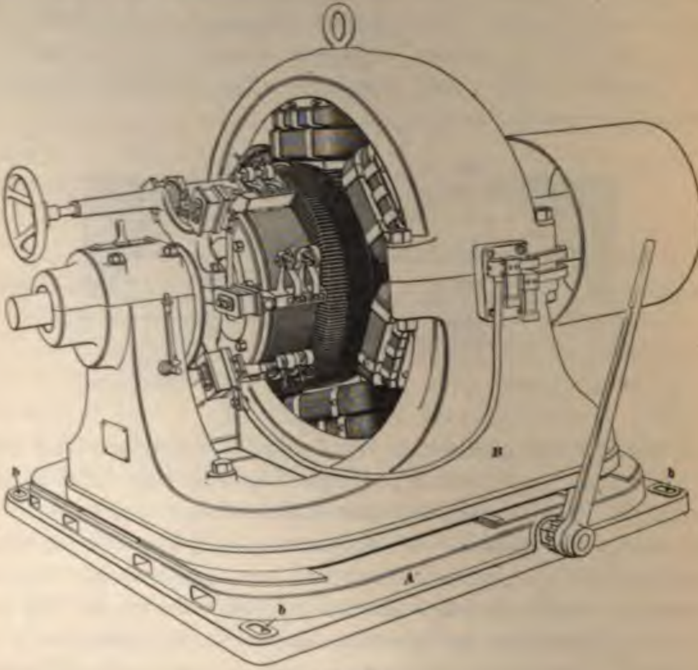

FIG. 2

No man should try to assemble the parts of a heavy machine without being provided with the rigging devices adapted to the work. Large stations provided with large units are generally equipped with cranes to replace armatures or fields that may become burned out. Small stations are not so well fixed, so the installer must usually look them up for himself. As the construction of machines varies to some extent, so must the method of handling the parts. In order to be specific, the machine shown in Fig. 2 will be taken as the one to be assembled. This is a six-pole belt-driven street-railway generator of the Westinghouse type. The bedplate *A* and the lower half of the machine *B* are worked on to the foundation by means of crowbars and rollers; as the wooden sub-frame projects above the level of the floor, a false wood floor must sometimes be laid. The bedplate is then worked into such a position that the holes *b*, *b* in the four corners of the foot flange fall just over the bolts or bolt holes that they are intended to engage. The blocking is then taken out and the machine let down upon the foundation or frame, as the case may be.

4. The next step is to place in position and connect together the bottom field coils *c*, *c*; the field coils may be put in the top half of the frame at the same time, so that this part can be swung into position as soon as the armature is in place. Great care must be taken that the coils are slipped over the pole pieces with proper regard for the marked ends, or trouble will surely result. Field coils that do not weigh more than 200 pounds may be safely lifted into place; but great care must be taken not to bruise the insulation or bend or break the terminals. For handling heavier coils than this, and also for handling the armature and top half of the frame, tackle must be rigged immediately above the foundation. In rigging this tackle, the total height that the top half of the frame must be lifted to get it in place after the armature is in position must be considered. If a chain hoist must be used, do not attempt to lift a 4,000-pound armature or top field half with a 2,000-pound hoist—use a 4,000-pound hoist, or even two 2,000-pound hoists. To support the hoist, a rope is slung in several turns from a roof girder or from a crosspiece laid between two girders. Old cloth or carpet is interposed between the rope and the girder so that the former may run no chance of being cut. The hoist is hung at such a height as will enable its full hoisting range to be utilized. If in spite of all that can be done, the hoist does not have sufficient range for the highest lift, the lift will have to be divided into two stages. These two stages must be such that the end of the first lift leaves the part to be lifted as near to the floor as possible. The part is then securely blocked, the point of support of the hoist raised, and the lift completed. To put the armature in place, it is moved as close as possible to the machine, so that its tendency to swing in, due to its being out of the vertical line of the hoist, will be a minimum. This tendency must be further offset by means of a strain put on by a block and tackle or hand line applied at the side. The bearing parts of the armature shaft should be encased in cloth before lifting, to avoid nicks and dents. The pillow-blocks should be inspected to see that they contain no iron filings or other dirt, and should then be filled with a good quality of oil.

5. Under no circumstances should any of the weight of the armature be supported by any device in contact with the commutator; the point of support should always be the shaft. For handling small armatures whose pillow-blocks are removable, a couple of ordinary handle bars, such as those shown in Fig. 3, should be used, and for the heavier ones a rope sling *S* and spread bar *B* such as are shown in Fig. 4; note that the rope is crossed on itself when it passes through the hook. When handling a heavy armature, its commutator should be protected by a blanket or other padding to save it from knocks that may dent a bar or damage

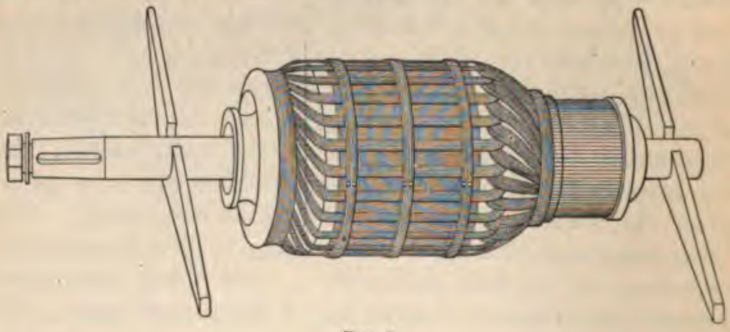

FIG. 3.

a band; the armature should not be rolled over the floor carelessly, as a nail head or a piece of hard matter of any kind in its path is liable to nick a band wire, so that as soon as the machine is up to speed and heated, causing some expansion, the band wire will break. As soon as the armature is swung over its final position, the shaft is wiped off with clean waste and served with a thin film of good cylinder oil. The bearings are then slipped on; in doing this, the oil rings must be lifted by running a clean round rod or stick in the end, otherwise the end of the shaft may jam one of the rings and bend or break it. Where spiral bearings are used, care must be taken to put them on the shaft as the marks call for, otherwise the oil will be fed out instead of in, and the box will run hot. All these points being looked after, the armature is dropped into place and given a few turns by hand to see that the oil rings work and that there is enough end play to prevent binding. Using the pulley end of the shaft as a straightedge, the machine is now leveled by means of a spirit level, split sheet-iron washers being put under the bedplate around the anchor bolts if one end must be raised.

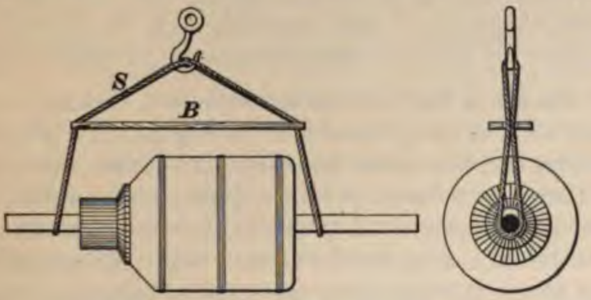

FIG. 4.

6. If the foundation and frame have been well made, little or no lining will be called for. With the armature in place, the top half of the frame, whose field coils have been previously connected, is lifted on. The joint between the top and bottom halves should be well cleaned before setting them together; it may be necessary to wipe off some white lead, put there to prevent rust, or to surface down a dent due to a falling tool. Where the machine has detachabl pole pieces, the same care should be exercised in regard to th surfaces between them and their seats on the frame. Whe the top half is in place, the pulley is put on, the machin lined up to the engine that is to drive it or to the pulle that it is to drive, and the yoke, brush holders, and othe fittings put on. The driving belt should have a cemente not a laced, joint. It must be borne in mind that in orde to make a good job of lining up the motor or dynamo, it i necessary that the device to which it is to be belted ha been installed with the same care as the dynamo itself.

7. Starting Up.—If the machine is a dynamo, it is, c course, started up by means of its engine; if a motor, cu rent from the line must be used. In either case, be sur that there are no tools or other parts lying on the belt o on the dynamo where they can shake off on to the armature or be sucked up by the fields. The machine should b run at about half speed for an hour or more to give ba bearings a chance to show their presence and to see tha the oil rings do not stick. If all the parts of the machin seem to be in good working order, the speed can be run u to its normal rate, and the machine given a chance to pic up its field, but no load should be put on for several hour Where the parts of a machine have been exposed and ar damp, the insulation will be low, and arrangements shoul be made to bake the windings with current at low voltag so that there may be no risk of a burn-out at the start; bu in testing the insulation of a machine that is running on grounded circuit, such as a street-railway circuit, unless th permanent ground is removed, the insulation will, of cours show a dead ground.

8. The machine should be turned over very slowly at firs so that in case it is not lined up exactly right the belt will no run off before the necessary change can be made; shoul the belt try to come off, it can, as a rule, be held on with bar until the machine can be stopped; even if the belt does come off on the *outside* of the pulley, no special harm is done; but if it comes off *inside* of the pulley, it is liable to have one of its edges curled and stretched and it will give constant trouble afterwards. On this account, it is a good plan, if there is any doubt as to whether the pulleys are in line, to cant the machine pulley a little in favor of the outer edge.

9. In order for a dynamo to pick up its field, it is necessary that the fields have a little residual magnetism left over from the last charge. Electric machines, except some of the largest sizes, are always tested under load before they leave the factory, and, as a rule, retain enough of the magnetism to "pick up" on when they are installed. But sometimes on the way from the factory to their destination this magnetism is not only vibrated out of them, but in some cases the vibration has been known to reverse the polarity of the dynamos. Even machines in service a long time lose or reverse their residual magnetism for no apparent reason. In such cases, the fields must be recharged. In the case of an isolated machine, this recharging must be done from a battery, unless there is some other machine in the neighborhood that can be temporarily tapped to the outside line; where there is more than one machine, the field of the dead one can be charged from the live one; in such a case, the field leads must be either disconnected or the brushes lifted off the commutator of the dead one, to avoid running it as a motor. Of course, in the case of a motor, the field current is supplied from the line, so that with motors there is no trouble on account of the fields losing their magnetism.

OPERATION.

10. General Care of the Machinery.—The dynamo or motor and all devices connected with its operation or regulation should be kept perfectly clean. No copper or carbon dust should be allowed to accumulate to cause breakdowns in insulation. The oil gauges and grooves should be kept in working order and the oil in the wells should be renewed at regular intervals. The brushes should be kept clean. They should be set and trimmed to fit the commutator, and copper brushes should be taken out once in a while, whenever they become clogged, and dipped in gasoline to cleanse them. When a machine is shut down, copper brushes should always be lifted just before the dynamo comes to a stop and they should not be let down until the machine, if a dynamo, is under headway again. New carbon brushes should be sandpapered to fit the commutator, by sliding a piece of sandpaper back and forth between them and the commutator. Do not use emery paper for cleaning the commutator, as emery is more or less of a conductor and may cause short-circuiting between the bars; also small pieces of emery become lodged in the brushes and scratch the commutator. The connections and all setscrews and bolts should be inspected regularly to see that none are liable to become loose and fall out. All screws that secure shunt-field or rheostat wires should be fixed by a drop of solder.

Oil should be used very sparingly, if at all, on the commutator; to lubricate it, put a film of vaseline on a canvas cloth, fold the cloth once, and let the commutator get only what goes through the pores. Never allow a loose article of any kind to lie on any part of a machine. Oil cans should be made of brass so that they will not be attracted by the pole pieces. Do not allow a belt to run tight enough to cause a hot box, nor let it run so loose as to squeak and threaten to come off. When closing a switch, do not tap it in to see if everything is all right, but once the mind is made up that everything is as it should be, close the switch firmly. The operator's eyes and hands are of more importance and value than anything else in the station. If there is any doubt about whether a switch should be closed or not, do not close it until all doubt is removed. All switches should be left open when the machine is not in action. Circuit-breakers should be tried at frequent intervals to see that they are not stuck or set for the wrong load.

BRUSHES.

11. On direct-current machines, the brushes and commutator require, perhaps, more attention than all the other parts of the machine put together. Brushes should in the first place be of sufficient size to carry the full-load current of the machine without heating. Brushes are of two kinds: *radial* and *tangential;* **radial brushes** point straight at the center of the circle that represents the outline of the commutator; their direction is parallel to the radius, as shown in Fig. 5 (*a*). **Tangential brushes,** Fig. 5 (*b*), are generally made of copper and are found, as a rule, on lighting machines. Radial brushes are made of carbon and are mostly found on power machines, though they are now largely used on lighting machines as well. Carbon brushes are used on machines whose output is at a comparatively high voltage, and, hence, low current; copper brushes, on machines of high current and low voltage. Also, carbon radial brushes are used on machines that must admit of being reversed in rotation. Carbon brushes are generally found on machines subjected to sudden and violent variations of load, while copper brushes are better adapted to conditions of slowly varying or constant load. Carbon brushes are usually copper plated to within $\frac{1}{4}$ inch or $\frac{1}{2}$ inch of their bearing ends, in order to give them better contact with the brush holders. Also, carbon brushes often contain a lubricant in the form of the paraffin with which the carbon dust is treated in the course of its manufacture, so that these brushes being self-lubricating, no compound or grease is needed on the commutator itself. With carbon brushes, the commutator takes on a dark-chocolate polish and the brushes emit a squeaking noise at starting or stopping.

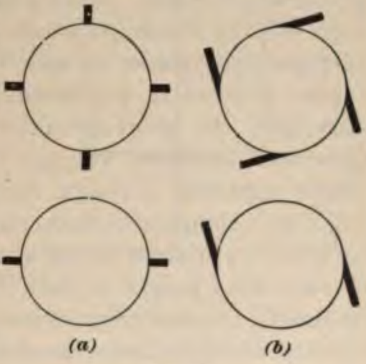

FIG. 5.

12. Carbon brushes are made in several grades of hardness, adapted to different conditions of working and different kinds of commutators. In stationary, direct-current work, soft carbon is used; on street-car work, hard carbon. Carbon has the great advantage that, being of relatively high resistance, it limits the value of the current generated in the coils that are short-circuited as they pass under the brushes and thereby reduces the sparking. By reason of this fact, carbon brushes admit of a wide variation in the load and hence in their non-sparking positions, without giving any trouble. This is why carbon brushes are used on high-voltage dynamos where there are sudden and violent changes that cannot be met by shifting the brushes. With copper brushes it is different; copper is of such low resistance that the short-circuited coil passing under a brush generates sufficient voltage to force a large current that causes sparking through the local circuit comprising the coil, two commutator bars, and the brush. This condition occurs if a variation in the load leaves the brushes out of the non-sparking points, so that copper brushes must, as a rule, be shifted to meet any variations in the load. Many kinds of copper brushes have been devised to meet this objection; in every case the object has been to increase the resistance in the path of the short-circuited coil without increasing the resistance to be traversed by the main current of the machine. To this end, brushes have been made of alternate layers of copper and of carbon, or have been made of copper wires or gauze.

In Fig. 6, *A* is the ring armature of a dynamo sending a current through lamps *L* by way of brushes $a+$, $a-$; coils *c*, *c* are passing under the brushes and are, therefore, being short-circuited by them through the local loops, *1-2-3-4-5-6-7*. It is not hard to see that if the center of the brush throughout its width be made of an insulating material, as indicated by the dotted lines, the local current due to the short-circuited coil cannot get from the heel of the brush to the toe, or *vice versa*, without first flowing up and down the full length of the brush, so that the short-circuited coil cannot generate so large a current, although the flow of the current in the main circuit of armature and lamps is not interrupted. On account of its decreasing the capacity of the brush, and for other reasons, it is not desirable to break the short local circuit, but a compromise is made by constructing the brush of alternate layers of copper and carbon or some metal whose specific resistance is high enough to reduce the current in the short-circuited coil, but not high enough to offer any serious impediment to the flow of the main current. Copper brushes are never made solid; they are made flexible, in one way or another, so that they may more readily conform to the surface of the commutator and bear at as many points as possible.

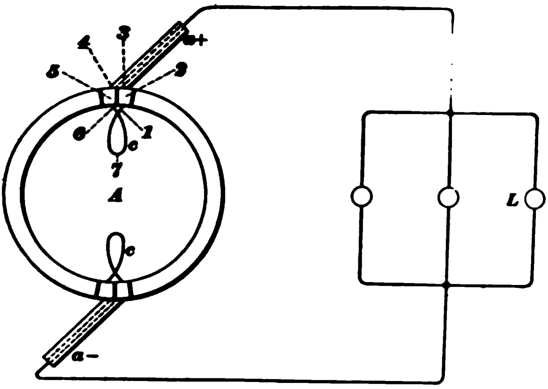

FIG. 6.

13. Ordinary copper brushes are not strictly tangential, this type being used only on small machines and on arc-light machines where the current is small. A form of strictly tangential brush is shown in Fig. 7 (*a*). Carbon brushes are often made as a kind of compromise between the tangential and the radial types, as shown in Fig. 7 (*b*). Just as in the case of the most common form of copper brush, it is neither exactly perpendicular nor parallel to a radius of the circle representing the end view of the commutator. No matter what style of brush is used, it sh bear against the commutator with the proper tension. All generator brushes and stationary-motor brushes are so arranged that the tension can be regulated. Portable motors (street-railway motors) are not so fortunate. They are so limited in point of space and accessibility that the brush-holding device must be designed to average the right tension throughout the life of the brush.

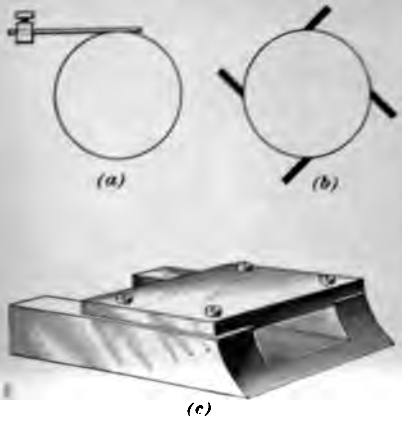

FIG. 7.

The tension that a brush spring must have depends on the material and condition of the commutator and on the material of the brush itself. A copper brush does not, as a rule, call for as much tension as a carbon brush, and soft carbon will run with less tension than hard carbon; a rough commutator needs more brush tension than a smooth one; for given brush contact, large currents call for more pressure than small ones. Finally, where there are several brushes in each holder, the tension must be the same on all, so that they will all take about the same current. This tension should be great enough to pass the current without sparking or heating, but it should not be great enough to wear out the commutator unnecessarily. One of the features most conducive to success with brushes is the proper setting of them; this subject will be taken up in the article on "Sparking."

If the contact between the brush and the commutator is loose, the contact resistance will be high and heating will result. On the other hand, increasing the pressure beyond a certain amount results in very little reduction of resistance, but greatly increases the friction. For stationary work, a pressure of 2 to 2½ pounds per square inch of brush contact surface should be sufficient. For railway work, the pressure has to be much heavier on account of the jarring to which the motor is subjected.

14. One of the greatest weaknesses of carbon brushes is that they, at times, stick in the holder so that the tension spring is not strong enough to force down the brush to its place, and even if it does force it down, the pressure on the commutator will be too light. This very serious fault may be due to either of two causes: lack of uniformity in the thickness of the brush or an excess of paraffin in the brush. If a brush is thicker at one end than it is at the other, it may go into the holder freely if put in thin end first, and might not go in at all on the thick end. The result of this is that as soon as the brush wears down to a point where the thick end enters the holder it sticks. On the other hand, the fault may be due to a nick or burr in the brush holder itself. The only way to get rid of all chance of such trouble is to have a hard-steel gauge for the brushes and another for the holders; discard all brushes that will not pass through the brush gauge freely and file out any holder that will not take the holder plug gauge. As a final check against a bad brush getting into use, always try the brush in the holder end for end. The common practice of sandpapering a brush to get it in is a very bad one, as it not only makes the brush lopsided, thereby impairing its contact with the main surface in the holder, but it also takes off the copper plating.

The second source of trouble—an excess of paraffin in the brush—is accounted for as follows: If a carbon brush is snugly fitted into the holder so that it slides back and forth freely, but without any clearance, while the holder and brush are cold, as soon as they become warm the paraffin oozes out, forms a paste with whatever carbon or copper dust there may be present, and causes the brush to stick. It is a very common occurrence to see brushes that have been giving trouble coated with a tough skin of carbon dust and paraffin that can be readily scraped off with a knife. It is very essential that the brushes should be kept clean and trimmed to fit the commutator; to trim them, an iron jig similar to that shown in Fig. 7 (*c*) should be used so that the bevel may be kept perfectly true. This jig is intended more particularly for filing copper brushes. Carbon brushes can be sandpapered to shape in place.

THE COMMUTATOR.

15. The **commutator** is the most sensitive part of a machine and its faults are liable to develop more quickly than those of any other part. When a commutator is in the best possible condition, it becomes a dark-chocolate color, is smooth, or glazed, to the touch, and causes the brushes, if of carbon, to emit a characteristic, squeaky noise when the machine is turning slowly. Under no circumstances should any weight be allowed to rest upon the commutator, nor should it be caught with a sling when the armature is being lifted. The commutator should preferably be set upon a tapered seat on the shaft, forced up to its seat, and secured with a nut and lock, besides being provided with a key to prevent turning. With such an arrangement, the problem of putting on or taking off a commutator is very much simplified. Great care should be taken to eliminate every possibility of the device becoming loose, as such a defect gives rise to others, among which can be named open-circuited leads and consequent sparking. Great care should be taken to secure the best insulation between the bars and the shell, and from bar to bar, as a breakdown in the commutator insulation has the same effect as a breakdown in the insulation of the armature winding itself. The commutator bars should be perpendicular to a plane at right angles to the shaft, so that the brushes will not, in effect, set on a diagonal and cover more bars than they should. To secure the best results, the brush holders should be set as close to the commutator as possible, so as to do away with chattering. This is most desirable on machines that are to run in both directions, and the brush holder should, on such machines, be designed to slide radially inwards, so that wear in the commutator can always be readily compensated for.

16. If a dynamo or motor is not abused with too much overload, if the brushes are set properly, and if the commutator is made of the proper material, it should seldom get rough. As a rule, sandpaper and emery cloth are used around machines much more than they should be. For ordinary roughness of the commutator, due to some temporary abnormal condition, it is well enough to use sandpaper, but for chronic roughness some more permanent cure must be applied, as there is some serious cause behind the trouble. Take any of the following troubles, for example:

If a commutator, when it is built, is not properly baked or screwed down after it is baked, it is liable to bulge out in the course of time under the action of the heat due to its normal load and the centrifugal force, or it may develop loose bars. In the case of the bulging of one side, sandpaper will not do any good, because from the nature of the way in which it must be applied, the low part gets as much sandpapering as the high part and the relation between the two is kept the same. The best thing to do with a commutator that bulges badly is to take it off, bake it so as to loosen the insulation, tighten it up well, and turn it off in the lathe. For ordinary curvatures of surface, that is, unevenness due to wear, it is customary to set up a tool post and slide rest on the bedplate of the machine itself and turn off the commutator in position.

If the machine is a dynamo, it is run from its engine, which must be run very slowly; if the machine is a motor, its speed must be cut down by putting a water resistance in series with the armature but not with the field; in either case, a tool with a diamond-shape point must be used and the speed must be such that the bars will not be burred nor the nose of the tool burned. Keep the cutting point just about opposite (but a trifle above rather than below) the center of the commutator. After the commutator is turned, it should be smoothed off with a file and sandpaper, any burrs between the bars should be picked out, and vaseline sparingly applied through the pores of a coarse canvas rag. Always have the brushes raised when sandpapering a commutator, even if the machine has to be given a start and allowed to run on its own momentum, because, otherwise, the brushes will catch all the dust, with the result that they are apt to get clogged or the commutator become scratched. Outside of this, it is dangerous to sandpaper a machine that runs with an excited field and at a high speed, because the flying copper dust might be the cause of a short circuit that will burn the operator. This has happened more than once.

A narrow scratch or several of them all around the commutator means that there are particles of hard foreign matter under one or more of the brushes; the best thing to do is to take out the brushes and clean them. A broad scratch around the bearing surface of the commutator probably means that one of the brush holders has been set too close or has become loose and slipped down to a point where it touches the bars. The same scratchy appearance around the ears of the bars probably means that the armature has too much end play or that one of the brush holders is set over too far.

17. High Bars.—A metallic click emitted twice, four times, or six times (according to the number of brush holders in use) per revolution, indicates a high bar in the commutator; in such a case, the brushes will be seen to jump a little when the high bar passes under them. A high bar can come about in either of two ways: it may be due either to a loose bar working out or to the fact that one bar is much harder than any of its neighbors, and, therefore, does not wear down at the same rate. If the high bar seems to be firm under a blow from a hammer, it will be safe to take it down with a file while the armature stands still; but if the hammer test proves the bar to be floating, it is a serious matter, and nothing short of a regular repair job will give satisfaction. In testing a bar or bars with the hammer, care must be taken not to nick or dent the commutator, as such a defacement will cause the high-bar click to be emitted and it will be misleading.

18. Low Bars.—A fault very much akin to a high bar but much more serious in most cases, is the low bar, which gives forth very much the same sound, but the brushes drop, instead of rising, as the fault passes under them. The low-bar trouble may be due to any of several causes: it may be due to the commutator having received a severe blow in the course of handling; to one or more bars being of poorer material than the rest; or it may be due to the gradual eating away of the bar on account of sparking at that particular place. On any but ordinary bipolar machines, a loose connection will generally affect more than one bar. The main difference between a high bar and a low one is in the amount of work required to remedy them. A high bar can be removed by filing down or turning down that bar alone to the level of the others, but to get rid of a low bar, the rest of the commutator must be brought down to its level. This means that unless the low bar or flat is very slight, the commutator must be turned off. There are several other faults pertaining to commutators that will be taken up under the head of "Sparking."

19. Of course the most serious condition is to have a commutator that is poorly made and of poor stock. If the mica and copper used are not of the proper relative hardness, one will wear down faster than the other, leaving the surface of the commutator a succession of ribs. If the mica is too soft, it will pit out between the bars, leaving a trough to fill up with carbon dust and in a degree short-circuit the

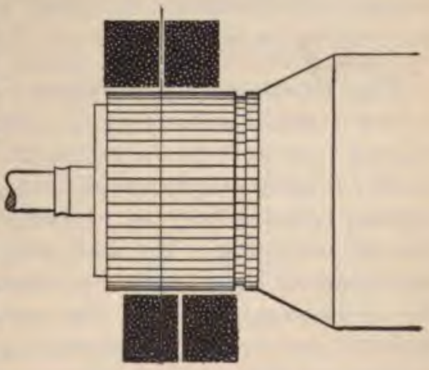

FIG. 8.

neighboring armature coils. If the mica bodies are too hard or too thick, the bars will wear in ruts and call for frequent turning down. The best combination for all-round work is made of soft, clear mica and hard-drawn copper. One practice of the day, and one that tends to materially increase the life of a commutator, is to so design the shape of the commutator bars and the set of the brushes, and to so proportion the end play of the armature that the brushes will play over the whole wearing surface of the commutator.

Fig. 8 shows such a disposal of the brushes, which are said to be **staggered.** The plan is to have the brushes so disposed that no ridges can be formed either on the outside edges or center of the commutator.

THE ARMATURE.

20. Armatures should be handled with great care, as it is an easy matter to bruise a coil or a lead, and this may not be noticed until the machine is started up and the trouble begins. All armatures should be supported by their shafts as much as possible, and should not be rolled around on the floor at the risk of having a coil punctured or a lead broken. When lying on the floor, they should lie upon padding of some sort. Extra armatures not in use should be kept housed in a dry place. The bearings and end play of the armature in use should be closely watched so that the core may not be let down on the pole pieces.

21. Heating of Armatures.—An armature should run without excessive heating; if it heats so as to give off an odor, any of several things may be the matter with it. It may be damp—a condition that, as a rule, is shown by steaming, but which can be better determined by measuring the insulation to the shaft with a voltmeter. This insulation should be at least 500,000 ohms when the machine is hot. If less than this, the armature should be baked, either in an oven or by means of a current passed through it in series with a lamp bank or water resistance. In using a water rheostat watch it closely, for the current increases as the water becomes hot. The baking current should not exceed the full-load current of the machine. In applying the current to the armature, be sure that the series field, if the machine has one, is not included in the circuit, and that the shunt field is broken; for if either field is on, the machine may start up as a motor. A machine that is too damp to run will heat at no load as well as at full load.

22. Another cause of heating under no load is due to the commutator being partially short-circuited all around from bar to bar, so that even when the coils are in the most active part of the field, a strong current can be set up through the local circuit provided by the coils themselves, the commutator bars to which their ends are attached, and the defective insulation between these bars. Such a condition often arises on an old machine, where the oil applied to the commutator has soaked into the mica bodies and carbonized. There is a case on record where the commutator was so short-circuited in this way that the machine would not start as a motor, because the applied current passed through the commutator instead of through the armature coils. The only true remedy for such a trouble is to put on a good commutator. Temporary relief can sometimes be obtained by taking a deep cut off the commutator, thereby removing the most defective part of the insulation.

23. If instead of the whole armature running hot, the heat is confined to one or two coils, the indications are that there is a short circuit either in a coil or between the two commutator bars that the ends of the coil connect. Such a short-circuited coil run in a fully excited field will soon burn itself out. A short circuit of this kind can be readily detected by holding an iron nail or a pocket knife up to the head of the armature while it is running in a field; any existing short circuits in the coils or commutator will cause the piece of metal to vibrate very perceptibly. One or more coil connections reversed on one side of the armature will, on a dynamo, cause a local current to flow from the strong half to the weaker half, and thereby cause all the coils to heat more than they should, besides decreasing the effective E. M. F. of the machine. On a motor, the effect is to decrease its counter E. M. F. so that it will take more current under given conditions, while the side containing the reversed coils will be hotter than the other side. The test for such a condition is to pass a current into the coils, one at a time, through the commutator bars, and to hold a compass needle over the coil that is connected to the two bars being fed; as soon as the reversed coils are reached, the compass needle will reverse the direction of its deflection. The coils must be disconnected and their ends reversed.

24. A broken armature lead or an open-circuited coi soon declares itself by causing a spark to travel around th commutator. A grinding, rumbling noise accompanied b excessive sparking and perhaps some slipping of the belt indicate that the bearings have worn down, letting th armature rub on the pole pieces. This is a trouble that takes place too often, and there is no excuse for it, for even if one does not know how long a set of bearings should run, he can easily tell how much wear has taken place by gauging the distances between the armature core and the top and bottom pole pieces. In such a case, the whole surface of the armature becomes hot and the bottom pole pieces and armature core show signs of abrasion.

25. An armature will sometimes get very warm through no fault of its own, but through heating from an abnormally hot bearing. Heat due to such a cause can generally be detected by the odor given off by the hot oil. Another serious trouble to which armatures are liable, especially motor armatures, is a bent shaft; this causes a very characteristic rattling noise to be emitted, the brushes spark, and the belt sometimes wabbles. The only thing to do with a bent shaft is to take out the armature and straigh shaft. After straight shaft it may be nece turn down the commutator before it will run true, as the bend in the shaft may have existed to a slight extent for several months.

26. One very peculiar fault to which armatures are liable is known as a **flying cross.** This is due to a loose wire that only gives trouble when the armature is in motion. The loose wire may either be broken, it may have a loose connection, or it may have defective insulation that allows it to come into contact with other wires as soon as the armature comes up to speed. In any case, the fault gives no trouble as long as the armature is at rest, but as soon as it gets up to speed, the centrifugal force throws the loose wire out of place and causes the brushes to flash. If not located and removed, the fault will, in time, burn a hole in the armature insulation.

27. Overloaded Armatures.—One of the most common causes of general trouble and heating in an armature is overload; this may be due to ignorance or neglect or to an error in the instrument that measures the load. There is a great tendency on the part of owners to gradually increase the load on a machine until it may be doing about twice the work it is intended to do. If the machine is a dynamo, lamps are added to its load one or two at a time; in this way it is an easy matter to overload a dynamo without intending to. If the machine is a motor, small devices may be put on it, one at a time, until an overload is the result. Another very common way of overloading a machine is to increase the voltage at which it is run. Many operators have the idea that as long as the current through the armature does not exceed its proper value, it does not matter what the voltage is, as long as it is not high enough to break down the insulation. The load on a machine is given by the product of the current and the voltage, hence the voltage has a direct influence on the load. If the voltage on a machine is doubled and the current is kept the same, the load on the machine [illegible]led. Therefore, in order to keep the maximum load the same on a machine whose voltage has been raised, say 25 per cent., the maximum allowable current should be lowered 25 per cent. If the machine is rated at 100 volts and 50 amperes, and it is decided to run it at 125 volts, the current, to give the same load as before, should be 40 amperes. Where machines are running together in multiple, one may be taking more than its share of the load, due to poor equalization. Ammeters sometimes get out of order, read incorrectly, or stick; the needle may stay in one place while the load makes a change of 25 per cent., and the machine tender will be none the wiser.

28. When a dynamo is overloaded the commutator becomes rough, the brushes burn up and spark, the belt squeaks, and the machine grows hot all over. If it is possible to find a non-sparking point for the brushes at some intermediate load and at no load, this should also be possible at full load. If it is not possible, the symptoms point to overload and the ammeter should be tested. Of course, some machines spark badly no matter whether they are overloaded or not. This is specially true of the older types. When a machine persists in sparking when the commutator and everything else about it is in good condition, the trouble may generally be attributed to poor design. Some machines are so poorly designed that it is practically impossible to keep them from sparking.

FIELD COILS.

29. We generally have two kinds of **field coils** to deal with, namely, *shunt* and *series*, or both, depending on the style of machine. These may be further subdivided into two classes, form-wound and shell-wound. Fine-wire fields are usually called **shunt fields** because they form a shunt or bypath for the armature current on a dynamo or the line current on a motor; they are of high resistance, so that they will take but a small part of the current supplied to or by a machine, and they are subjected to the full line voltage, as indicated in Fig. 9 (*a*), where *A* is the armature and *f* is the shunt field. Coarse-wire fields are usually called **series fields,** because they are in series with the armature, and should be able to carry the current that flows through the armature. They are of low resistance so that they may consume as little as possible of the voltage supplied to or by the machine, and as a result are subjected to but a small

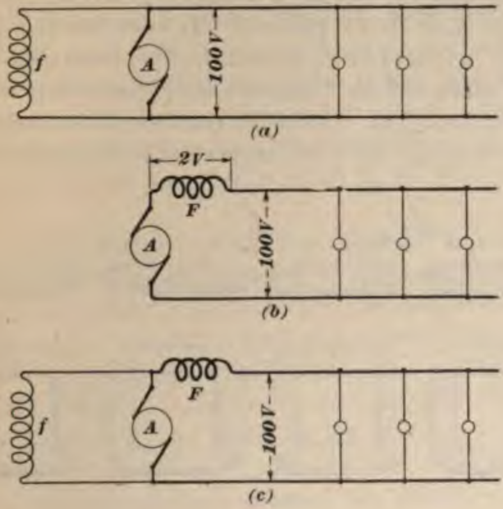

FIG. 9.

E. M. F., as indicated in Fig. 9 (*b*), where the drop through the series coils is supposed to be 2 volts. No matter what kind of field may have to be handled, the coils, leads, and connecting lugs should be handled with great care. The bearing surfaces of the coil should be brushed off before the coil is put in place, to avoid having any chips of foreign matter mashed into the insulation when the field bolts are screwed home.

30. Field coils should be installed in such a way that when the current passes through them, if one pole piece is called north, the poles on both sides of it will be south. Coils, as a rule, are marked so that the workman may know exactly where they are to go and which end is to point toward the commutator. It is usually easy to tell by the shape of the field which face of it is to go next to the frame of the machine and which next to the armature. If the coils are not marked or if there is any doubt about the marks, the matter can be settled as follows: Set the field coils on the floor and line them up on edge, as shown in Fig. 10; connect them together and send a current through them. Get them, by trial, so that a piece of soft iron, held in the hand, will pass in an easy curve, as shown at *I*, from one coil to the other, the same end on. Should the piece of iron try to take the position shown at *I′* between any two coils, reverse one of them. When the coils are all turned so that the iron takes the curved path from one to the other, put them in place on the machine in this same relation, for then it is certain that they will alternate in polarity. A more certain test, perhaps, is to put the field coils into the machine as it is thought they should go (leaving out the armature), and test them with a compass or piece of soft iron the same as before. In using a compass, care must be taken that it does not stick, for then the lines of force of the field are liable to thread through it backwards and reverse its polarity; if this takes place just at the wrong time, it may be misleading. The reason for making the test without the armature in place is that the pole induced in the armature core opposite each pole piece is apt to influence the action of the compass.

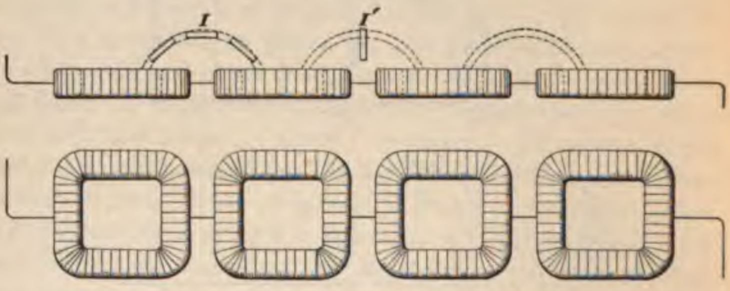

FIG. 10.

31. The effect of putting a field coil in end for end on a dynamo is to decrease the voltage that it will generate even on open circuit, and perhaps render the machine unable to generate at all. On a motor, the effect is to greatly increase the current required to start, to abnormally increase the speed after it is started, and to cause the brushes to spark. If a motor has only two fields and one of them is connected incorrectly, the machine will either not start at all or else it will start very slowly and take a very large current. A two-field dynamo cannot generate, under the same conditions even if excited from some other source, unless one coil happens to be a little stronger than the other, in which case the machine might generate a small E. M. F.

32. Where the machine is compound-wound, the two windings generally occupy parts of the same spool. Great care should be taken to get both sections properly connected. On a dynamo, if the shunt field as a whole is connected correctly but the series field incorrectly, the machine will pick up its field and hold it, but it cannot be made to take a full load; for as soon as the main switch is closed and current goes through the reversed series coils, their magnetizing force partially neutralizes that of the shunt coil, reducing the E. M. F. of the dynamo and fixing a limit above which the load cannot be made go. If the shunt fields are wrongly connected and the series field are correctly connected, the machine will not pick up its field at all on open circuit, and whether it will or not on closed circuit depends on the resistance of that circuit. This resistance must be very low for the comparatively few turns of series field to pick up through it, and even if it did, the resulting voltage applied to the terminals of the wrongly connected shunt field would bring about a neutralization of magnetism, and the E. M. F. would fall again.

33. On a motor it does not matter so much whether or not the shunt and series fields, as a whole, are connected to assist or oppose each other, unless the machine has been heavily over-compounded to run as a generator, in which case, if it is desired to use the series coils for maintaining constant speed under a variable load, it will be necessary to put a shunt in multiple with them. When a compound-wound motor is so connected that its series and shunt coils assist each other, it is said to be *accumulatively* connected, and it then has its greatest starting power for a given current. When the two fields oppose each other, the motor is said to be *differentially* connected, and if the strength of the two windings is in the proper relation, the speed of the motor will be constant within reasonable variations of load, if the voltage is constant. If, however, the series coils are too strong, the machine will run faster at full load than at no load, taking a great deal more current than it would with the reverse connection of the fields and perhaps sparking at the brushes.

34. Every dynamo, whether series-shunt or compound-wound, must have its fields connected in a certain way, in relation to the armature and the direction of rotation, or it will not generate. The direction of rotation of a motor depends on the connection of its fields and armature, and it can be reversed by reversing either of these, but not both. When a motor runs in a certain direction, a certain relation exists between the directions of the currents in its armature and field; when either of these currents is reversed, it changes this relation and with it the direction of rotation; but when both are reversed, which corresponds simply to changing the polarity of the dynamo that runs the motor, the relation remains the same and so does the direction of rotation. Exchanging the places of the terminals applied to a motor (unless it is separately excited) will not change its direction of rotation. For given armature and field connections, a shunt machine will run in the same direction as a motor that it does as a dynamo; a series machine will run in the opposite direction in the two cases, while the direction in which a compound-wound machine will run as a motor depends on the relative strength of the two windings and on the conditions under which the motor is started.

FIELD-COIL TROUBLES.

35. Fields, like armatures, are subject to troubles of various kinds; they are liable to open circuits, short circuits, and grounds. An open circuit can give rise to various effects, depending on the conditions under which the machine operates and also on the style of machine. In the case of a series dynamo, an open circuit in the field will render it totally incapable of operating either as a motor or a dynamo, but no harm can come to the machine itself, unless the fault should take place while the current was on, in which case it would be apt to burn a hole in whatever happened to be around the break.

36. On a shunt machine, the amount of trouble caused by the opening of a field coil depends on whether the machine is a motor or a dynamo; and if a dynamo, on whether it runs alone or in multiple with other dynamos. If the machine is an isolated dynamo, a break in the field coil can do no further damage than to prevent the machine from generating and, hence, cut off the current from whatever lamps or motors may be operated by it. If, however, the dynamo is in multiple with other dynamos on the same load, the result of such a fault will be that the other machines will send a large rush of current back through the faulty machine and cause, practically, a short circuit.

37. Series dynamos are not, as a rule, run in multiple. If a shunt dynamo that is ordinarily run as a dynamo is made to run as a motor by current being backed through it, it will keep on running in the same direction, but will spark at the brushes, owing to the fact that the brushes are in a place suited to dynamo running and not to motor running. If the dynamo is compound-wound, the direction that it will try to run when it becomes a motor depends on the position of its brushes and mainly on the relative strength of the series windings and shunt windings. Breaking the field of a dynamo in multiple with other dynamos amounts to the same thing practically as breaking the field on a shunt motor.

Breaking the field of a shunt motor destroys its counter E. M. F., so that there is no opposition to the line E. M. F. and there is practically a short circuit through the armature. As the field magnetism dies down slowly, the counter E. M. F. dies down also, and the short circuit does not take place so quickly but that the faulty machine may acquire a very high rate of speed and throw its belt or do other damage before the fuse or circuit-breaker acts.

38. An open circuit in the field of a shunt motor in action, then, results in a short circuit, abnormal speed, throwing off the belt, and opening the circuit-breaker. On a compound-wound motor connected accumulatively, the speed will not reach such a high value, because the series coils hold it down; but if the motor is differentially connected, as soon as the shunt field breaks, the series coils opposed to it bring the motor to a stop and start it up in the opposite direction. If the fault should occur while the motor is standing still, it would be impossible to start a simple shunt motor with a safe current. A compound-wound motor will, if the starting current is large enough, start up on the field provided by the series-turns; but it will start up in the wrong direction if the series coils are so connected as to oppose the shunt coils.

39. The effect of the reversal of a single field coil on a machine depends on how many field coils the machine has, in other words, the more poles a machine has, the less will be the effect of an irregularity in one of them. If the machine has only two coils and one of them is incorrectly connected, the machine will not start as a motor and it will not generate as a dynamo. If there are four field coils, it will take a heavy current to start it as a motor, and the brushes will spark even while the motor is starting. As a dynamo, most machines will refuse to pick up their fields at all, except at very high speeds, and even if separately excited, the voltage at normal speed will be below its proper value. On machines of more than four field coils, the same symptoms hold good, but to a less degree, and are characterized by sparking at the brushes that include the faulty field.

40. One other fault producing effects very much like the above is loose joints in the magnetic circuit. Where a machine has two halves fitting together, great care should be taken that no particles of foreign matter are allowed to get in the joint and so introduce an air gap into the magnetic circuit. The same precaution holds good in regard to machines having detachable pole pieces. The effect of a loose, or open, joint in the magnetic circuit, as in the case of a reversed field coil, is to weaken the field of the machine, so that on a dynamo there will be trouble picking up the field at normal speed, and the open-circuit voltage will be reduced by an amount dependent on the seriousness of the fault; while on a motor the starting current will be greater and the speed higher than it should be.

The effects are aggravated where the dynamo or motor is running in multiple with others. If a dynamo, it will be unable to meet the requirements of the rush hours, because its voltage cannot be increased enough to make it claim its share of the total load; it will require close hand regulation under varying loads, because its voltage will not vary at the same rate as that of its neighbors, although it may be the same kind of a machine. The best illustration of the condition applied to motors in multiple is found on an electrically propelled car where the two or more motors are practically rigidly connected within certain limits of load. The motors when doing their heaviest duty are in multiple, and the one whose path offers the least resistance takes the most current. The motor that has a reversed field coil or a loose, or open, joint in its steel frame, has a lower counter E. M. F., and hence has less apparent resistance; it will then be only a matter of time when this motor will cause the car to repeatedly blow its main fuse. The motor will become hotter than its mate, the brushes will spark, the commutator will blacken and become rough, the armature throw solder, and a final inspection will probably show that all the cotton insulation on the field wire is baked or charred.

41. Short Circuits in Field.—The action of a short circuit in a field coil depends on the kind of machine, the manner in which the field coils are connected, and whether the short circuit is a good or bad contact. Take a shunt dynamo, with four field coils; if the coils are in series, as in Fig. 11 (*a*), so that the voltage across each coil is only one-fourth of the total voltage, a good short circuit in a single coil will cause it to run comparatively cool, while the remaining coils will get unusually warm. A bad contact is apt to emit more or less of an odor of burning shellac and other insulation. The cutting out of a single coil in four will reduce the resistance of the field circuit so that more current may flow through the remaining coils in an attempt to make up the loss of magnetism due to the cutting out of one coil, but this automatic compensation will not be so much but that the field rheostat resistance will have to be lessened to keep up the dynamo voltage.

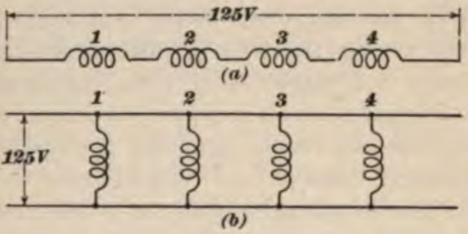

FIG. 11.

42. On the other hand, if the shunt coils are all in multiple, as shown in Fig. 11 (*b*), the faulty coil will be the one to get hot and the rest of the coils will run at normal temperature. If the fault is such as to cut out the coil entirely, the machine will loose its field, because a shunt machine will not support a field on short circuit. On a compound-wound dynamo running alone, a short circuit in the shunt winding will cause about the same symptoms, as far as the heating goes, as in a shunt machine. If the shunt coils are in multiple and connected as shown in Fig. 12 (*a*) (*short shunt* connection), the dynamo will drop its field if one shunt coil is dead short-circuited; but if the shunt coils, as a whole, are connected as shown in Fig. 12 (*b*) (*long shunt* connection), so that the series coils are in series with the

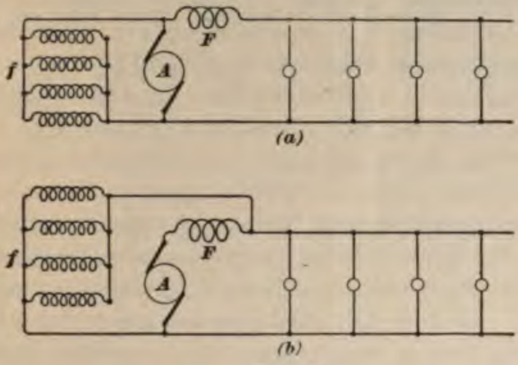

FIG. 12.

fault, the dynamo will throw its belt because the series coils work under the best possible conditions—a short circuit.

43. Moisture in Field Coils.—Moisture in field coils will cause them to heat and make the brushes spark. Before putting such fields into actual service, they should be baked out, either with the current or in an oven. Moist field coils, as a rule, steam when hot, feel moist to the hand, and their insulation to the frame of the machine measures low. The most refined way of locating a short-circuited field is to measure the resistance of the field suspected and compare it with that of a standard field of the same kind. A variation of over 10 per cent. should not be allowed, and where the fields are in multiple, not over 2 per cent. variation should be allowed. A short-circuited shunt field can be located by short-circuiting or cutting out one field coil at a time and measuring the open-circuit voltage of the dynamo.

44. Grounded Field Coils.—A grounded field is a very common source of trouble in some classes of work, but a very unusual one in others. Commercial circuits may be divided into two classes, namely, *metallic-return* and *ground-return circuits.* On metallic-return circuits, both the outgoing and return wires are insulated from the earth. Ordinary lighting and conduit trolley systems are examples of metallic-return circuits. Ordinary street-railway systems are examples of a grounded circuit, since the trolley wire constitutes one side and the ground or track the other. The indications of a grounded field depend on whether the machine is on a metallic-return or a ground-return system, and if on the latter, whether the machine is a dynamo or motor and what place the field occupies in the circuit.

Metallic-return systems are, as a rule, characterized by having very little trouble from grounds; because, in the first place, since neither side of the system is permanently grounded, there is but half the tendency for either side to ground; and in the second place, a single ground does not at all disturb the operation of the devices, because another ground is necessary to complete the circuit. Should two grounds develop, one on each side of the circuit, or at two places in a device, a short circuit follows; but, as a rule, a single ground can be detected and removed before another occurs to cause trouble. Lightning is responsible for many of the grounds on metallic-return circuits. Inasmuch as ground troubles are more common on ground-return circuits, we will devote our limited space to this class of work.

45. Fig. 13 shows a shunt dynamo at work on a grounded circuit, the ground return being indicated by the dotted line. Suppose a ground takes place at *a*; the result will be a dead short circuit across the line, under which condition the dynamo will drop its field. A ground at *d* will have no effect, as that side of the circuit is already grounded. A ground anywhere between *a* and *d* will cut out a part of the field and severely heat the part not cut out.

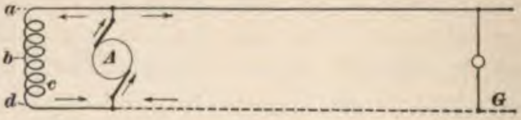

FIG. 13.

46. Fig. 14 shows a compound-wound dynamo with the shunt field connected inside of the series field. A ground at *a* will cause the dynamo to drop its field as before; a ground at *d* will not be felt. A ground at *b* will cut out a part of the field and the remaining part will heat badly; the voltage on the line will drop. Fig. 15 shows a compound-wound dynamo with the shunt connected across the terminals of the machine instead of across the brushes. This alters the conditions very much. A ground at *a* establishes a short circuit through the series field. The shunt field is cut out entirely and the line loses its power, but, owing to the strong current in the local circuit *A–F–a–d–A*, the dynamo throws its belt unless the circuit-breaker acts quickly. A ground at *b* will give the same indication as in the case of Fig. 14.

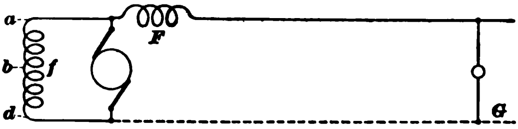

FIG. 14.

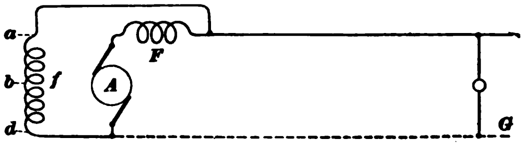

FIG. 15.

47. Fig. 16 shows a series dynamo at work on a grounded circuit. A ground anywhere on the field will cut the power off the line. A ground anywhere near *a*, unless the dynamo is of the arc-light type with very heavy armature reaction, will throw the belt. A ground anywhere near *b* will simply cut out the field and the machine will stop generating.

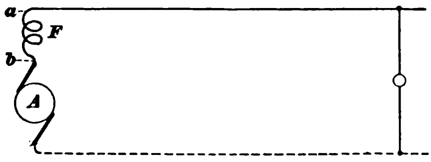

FIG. 16

Fig. 17 shows a series machine as in Fig. 16, but with the field next to the ground. A ground at *a* will cause the dynamo to stop generating; a ground at *b* might cause it to drop its voltage and it might not, depending on the amount of resistance in the load; if this resistance is small, the dynamo will generate a lower voltage. A ground at *d* will not be felt.

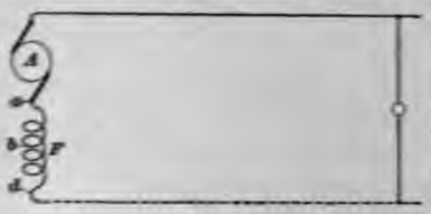

FIG. 17.

48. Let us suppose now that the dynamo in each of the above figures becomes a motor; the current, instead of coming from within the machine, comes to it from an outside source. In Fig. 13, then, a ground at *a* when the machine is running will cut out the motor so that it can get no power, the circuit-breaker will fly out or the motor will throw its belt, owing to the fact that in virtue of its momentum it will become a dynamo running on short circuit, both ends being grounded, one permanently and the other through the fault. The effects for the other grounds will be about the same as in the case of the dynamo.

In Fig. 14, a ground at *a* will cut out the shunt field and stop the motor very suddenly, as the armature will be grounded at both ends, and the series coils will be heavily charged by the current passing through the fault. The machine will really become a separately excited dynamo on short circuit. A ground at *b* will cause part of the field to heat badly, and a ground at *d* will have no effect.

In Fig. 15, a ground at *a* will cause practically the same action as in Fig. 14 and for about the same reason. In both cases, the motor will probably throw its belt. A ground at *b* and *d* will cause the same action as in the case of the dynamo.

In Fig. 16, a ground almost anywhere on the field, except at *a*, will separately excite a part of the field and bring the armature to a sudden stop, owing to its dynamo action through the short circuit. A ground at *a* can cause no action of this kind, because the dynamo has no shunt field; and although the armature is permanently grounded on one end and is grounded through the whole series field on the other end, it cannot generate, because a series machine runs in opposite directions as dynamo and motor, for given connections; so that the direction in this case is not the right one. The motor of Fig. 16 finds its practical parallel in the street-railway motor as it is today. Fig. 17 is the same thing, only the fields are next to the ground, so that a ground in a field coil does not cut out the armature.

In Fig. 17, a ground at *a* cuts out the field and the entire short-circuit current passes through the armature, causing violent sparking that burns the brushes and commutator. A ground at *b* cuts out all the field below it, weakening the field and causing the armature to take an excessive amount of current. A ground at *d*, as in former cases, has no effect at all. Placing the field next to the ground has the disadvantage that a ground may take place in such a part of the field that the armature may be overloaded a long time before the fact is known; but it has the advantage that, being on the negative side of the armature, the difference of potential between the positive side of the field and the ground is very small, so that there is not as great a tendency for grounds to develop as in the first case. It is a well-known fact that cars equipped with motors whose fields are next to the ground give much less trouble from grounded fields than cars whose fields are next to the trolley.

REASONS FOR A DYNAMO FAILING TO GENERATE.

49. Loss of Residual Magnetism.—Among the many causes which may make a dynamo fail to generate, loss of residual magnetism is often one of the most troublesome. The magnetism that remains in the steel or iron frame after the field current is cut off is called **residual magnetism,** and every dynamo must have a certain amount of this to start on before it can build up its field. As a rule, dynamos leaving the factory retain enough residual magnetism to start on, but there are several ways in which they can lose it; they sometimes lose it after having given no previous trouble of that sort in months or years. Some dynamos never lose their residual magnetism, or **charge**, it is called, while others seem to have a weakness for ing it.

In many cases the peculiar action cannot be explained; in me cases it may be due to any of the following conditions: (*a*) Excessive vibration; hence dynamo should always rest on a solid foundation. (*b*) To the earth's magnetism; where practicable it may be well set the machine so that its north pole is toward the north hen the earth's magnet-n will pass through the machin n the same direction as s own. The earth's magnetis s very weak, but when sisted by vibration it may somet s be sufficient to counteract the residual magnetism. Only two-pole machines can be really set to fill this condition, as on multipolar machines the poles radiate in all directions. (*c*) A dynamo set very near another dynamo; in such a case, stray lines of force from a loaded dynamo may thread their way through the magnetic circuit of an idle one in the reverse direction and neutralize its residual magnetism. (*d*) The fields accidentally given a slight flow of current in the wrong direction; this can very easily occur on a compound-wound or series dynamo, as current from the outside will always pass through the series coils in the opposite direction to that in which the current from the machine itself would pass. In shunt machines, however, this is not so, for as a motor, the field winding shunts both the armature and the line. (*e*) The machine started up with the fields or armature as a whole incorrectly connected, that is, reversed; in this case the result will be to destroy whatever residual magnetism there may have been. (*f*) The field circuit broken too suddenly; when a field circuit is suddenly broken, the residual magnetism is sometimes brought down to zero or even reversed.

50. Where a dynamo has lost its charge, the pole pieces will have little or no attraction for a piece of soft iron. There are several ways in which the charge may be restored. Series dynamos seldom lose their charge so entirely that they will fail to pick up a field on short circuit. Where a compound-wound dynamo refuses to pick up a field with its shunt field, it can often be made to pick up by disconnecting the shunt coils and short-circuiting the machine through a small fuse that will prevent damage due to the short circuit. The same idea in a modified form may be used on a plain shunt dynamo by temporarily connecting all the shunt coils in multiple instead of series. This makes the machine a series dynamo with a low-resistance circuit. Any machine can in many cases be made to pick up a field by simply short-circuiting the armature by holding a piece of copper wire across the brushes or by rocking the brushes back from their neutral position. The effect is to make the magnetism of the armature help the field to build up.

If none of these expedients produce the desired result, the fields must be recharged from an outside source. If the dynamo runs in multiple with other dynamos, this is an easy matter; it is only necessary to lift the brushes or disconnect one of the brush-holder cables on the dead machine and throw in the main-line switch, the same as if the machine were going into service with the others. The fields will then take a charge from the line and their polarity will be correct. After the field has been charged, the brushes or cable must not be moved until the main-line switch is open, because a short circuit will be made. If the dynamo does not run in multiple with another and there is a dynamo within wiring distance, disconnect the shunt field of the dead dynamo and connect it to the live circuit. The live circuit may be the trolley wire of a street-railway circuit. Bear in mind, however, that this is a 500-volt circuit, so that if it is to be used for charging 125-volt fields it must be applied for only a couple of seconds. There have been cases where it has been necessary to run a couple of wires a quarter of a mile, or more, to obtain current for charging a field. If there are absolutely no other means available for charging, several cells of ordinary battery must be used; connect the field coils in series with the cells in series and give the pole pieces of the dynamo repeated knocks with a hammer while the charging is going on; if this fails, reverse the terminals of the battery and repeat the operation—it may be that the first time the battery is applied its magnetizing force opposes what little residue magnetism there may be in the iron. As a last resource, when all other available sources fail, connect the fields so as to obtain the least possible resistance, put them in series with the armature through a small fuse, and speed the armature considerably above the normal rate. Very often a dynamo, instead of losing its residual magnetism, will acquire one of a reversed polarity, due, perhaps, to the same causes exercised to a greater degree. Except where the dynamo is used for charging storage cells, or for electroplating, or for running arc lamps, or for running in parallel with other machines, the reversal of its polarity can do no harm. In case an arc machine is reversed, the concave carbon will be the bottom one and most of the light will be thrown up instead of down, where it is generally desired.

51. Wrong Connection of Field or Armature.—Every dynamo requires that a certain relation exist between the connection of its field and armature and its direction of rotation, or it will refuse to generate. Suppose a dynamo to be generating; if its field or armature connection (either, but not both) be reversed, it will be unable to generate; or if all the connections be left intact and the direction of rotation reversed, the machine will be rendered inert. Not only is it unable to generate with the wrong connections or rotation, but a short run under this condition will render the machine unable to generate after the conditions are corrected, unless the field is recharged, because the effect is to destroy its residual magnetism.

Let us see why such is the case. It sometimes happens that when a dynamo is first started it has a small E. M. F. due to the residual field; but upon closing the field circuit, the E. M. F. falls to zero and the machine refuses to generate. Such action indicates a wrong connection of field or armature for the given direction of rotation and can be explained as follows: Suppose the dynamo to be properly connected and to be generating; this implies that the field current is in such a direction as to produce a magnetic field that reinforces the residual field. Now, without disturbing anything else, let the field terminals be reversed; for the sake of clearness, we will suppose that there remains a residual field due to the current last flowing. Under this condition, the lines of force due to the residual field are in the same direction as they were when the machine was properly connected and generating; the small current now generated in the armature, and due to the residual field, will be in the same direction as it was then, but the field connections being reversed, the current flows around the poles in such a direction as to neutralize their residual magnetism. The weak residual field is now opposed by this new field and soon the residual field is reduced to zero, thus totally depriving the machine of all ability to pick up. Nor can a reverse field, even if established by recharging, be maintained; for, assuming a reversed residual magnetism to be provided, the lines of force have changed direction, the armature current does likewise, and previous conditions being reestablished, the residual field is again destroyed. If, then, a dynamo fails to generate, and all other conditions are apparently correct, reverse the field leads and again try to make the dynamo generate. If a loss of residual magnetism is indicated by very weak poles, recharge the fields.

52. Open Circuits.—A series dynamo cannot, of course, pick up its field if any part of the circuit is open, for there is but one circuit. It cannot pick up its field if the resistance of its outside load is above a certain value peculiar to each machine, for as a rule series dynamos supply devices iat are also in series, and every device added means more esistance for the machine to pick up through. As it will not pick up through a high resistance, it is customary to provide ies dynamos with a switch, by means of which the line and hine are short-circuited at starting, so that the load is thrown on until the dynamo picks up, after which the t-circuiting switch is opened, leaving the line properly nected to its terminals. A shunt, or compound-wound, mo will not pick up if the shunt field circuit is open; open circuit may be in the field itself, in the field ostat, or in some of the wires or connections involved in circuit. A careful inspection will generally disclose any lt that may exist in a wire or connection; to find out if rheostat is at fault, short-circuit it with a piece of copper ; if the dynamo generates with the rheostat cut out, the is in the rheostat. To find out if the open circuit is in d coil, use a test-lamp circuit or a magneto-bell to test coils one at a time. Before doing so, be certain that all munication is cut off between the machine under test the line, if there are other machines on the same circuit. making this test, bear in mind that if the dynamo is compound-wound and connected as shown in Fig. 15, an open circuit in the series coils will cut off the current from the shunt coils also.

Connecting wires, in course of time, are liable to be shaken loose or broken by vibration; they should be made of flexible cable, and the screws that hold them may be secured against turning by means of a drop of solder. A field circuit is sometimes held open by a defective field switch that, to all appearances, is all right; repeated burning will oxidize the tip of the blade and make a blister on it; the blister will not carry current and it will press the jaws of the switch apart so that only the blister touches, and so opens the circuit. Another trivial but common cause of open circuits is the blowing of fuses. Fuses of the enclosed type give more trouble in locating the fault than any other kind, because it cannot be told by looking at them whether the fuse is intact or not.

An open circuit in the armature will interfere with the proper generation of the current, but such a fault, as a rule, announces its own occurrence in a very emphatic manner and does not, therefore, require to be looked for. A very uncommon source of open circuit, where copper brushes are used, is due to the burning of the brush heels into oxide. The dynamo will refuse to pick up until the brushes are trimmed and cleaned. When an armature just from the factory refuses to generate where the one just taken out has been generating, the trouble is probably due to either of two causes: There may be shellac on the commutator—in this case, a little coarse sandpaper will set things right; the armature may be a right-hand armature while the one taken out was wound left-hand, or *vice versa.* The expressions right-hand and left-hand here apply to features of winding or connecting, and should such a condition arise, it can be remedied by reversing the armature or field connections, or the direction of rotation.

Before attributing the failure of a dynamo to generate to any of the above open-circuit causes, see that the brushes are on the commutator, the field switch closed, and the greater part of the field rheostat cut out.

Always bear in mind that the E. M. F. generated when a machine is started up is very small because the residual magnetism is weak. It may not require a complete open circuit in the field to prevent the machine picking up. A bad contact that might not interfere with the working of the machine when it is up to full voltage might be sufficient to prevent its picking up when started. A loose shunt wire in a binding post or a dirty commutator will introduce sufficient resistance to prevent the machine from operating. Trouble is very often experienced in making machines with carbon brushes pick up, especially if the brushes or commutator are at all greasy. If such is the case, thoroughly clean off the commutator, wipe off the ends of the brushes with benzine, and see that they make a good contact with the commutator surface. Metal brushes, if kept in good order, do not give as much trouble as carbon in this respect, because their contact resistance is lower.

53. Short Circuits.—A short circuit on the line will make a shunt dynamo drop its field, but the dynamo may throw its belt before it does so. With a short circuit on the line, a shunt dynamo will not, therefore, pick up its field. Such a short circuit may be due to some fault in the pilot-lamp circuit, or it may be due to a motor switch being left in [illegible] ne by one of the outside consumers. On this acco [illegible] is to the interest of any company supplying power [illegible] otors to see that every motor is provided with an aut [illegible] tic cut-out, so that when the line voltage goes below a [illegible] tain value the motor circuit will open. With a series [illegible] ompound-wound dynamo, a short circuit on the line inc [illegible] es its ability to generate, because the fault is in series [illegible] h the series coils and its large current passes through t [illegible] n. A series dynamo, like a shunt dynamo, will not pic [illegible] up if the field is short-circuited. A compound-wound [illegible] ynamo will not pick up on open circuit if the shunt field is short-circuited; it will pick up with an open circuit in the main circuit, but will not hold its voltage under load if the series coils are short-circuited. In some cases a shunt dynamo will not pick up on full load, as this realizes too nearly the condition of a short circuit; so that to be on the safe side, it is best to let the machine build up its field before closing the line switch.

Short circuits within the dynamo itself generally give rise to indications that point out the location and nature of the fault. In any event, the first thing to find out is whether the fault is in the dynamo or out on the line; if it will pick up its field when the line switch is opened, but fails to do so with it closed, the trouble is outside of the dynamo. It may be on the switchboard, where a workman may have left a tool or piece of wire lying across the bus-bars. The most common method used to get rid of a cross on the line is to burn it out; this is done by centralizing the entire dynamo capacity of the station, if necessary, on the faulty circuit.

54. Brushes and Brush Holders.—In order for any direct-current dynamo to generate, its brushes must be in a certain position that depends on the type and design of the machine. As a rule, the design of the brush holder gives a clue as to where the brushes should sit, but one cannot say to a certainty where the brushes on a given dynamo should go unless he is familiar with that particular machine, because the position of the brushes is governed by conditions of winding and connecting not apparent to the eye. If the connections were brought straight out from the armature to the commutator bars, the brushes would always sit in line with the center of the space between the polar horns, because this is the position of the neutral field. But very often, for reasons of accessibility, the wires coming from the coils are given a **lead** that brings the normal position of the brushes in line with the centers of the pole pieces. The brushes on a motor sit the same as those on a dynamo, except that on a motor they are given a little lead backwards (in the opposite direction to that in which the armature rotates), while on a dynamo they are given a little lead forwards.

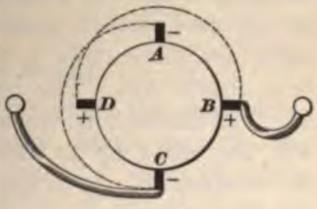

FIG. 18.

FIG. 19.

Fig. 18 refers to a four-pole machine with four brushes. The proper position for the brushes in this particular case is that shown in the diagram. *A* is on top, *B* to the right, *C* on the bottom, *D* to the left. If the rocker-arm be given a quarter turn to the right or left, so that, say, *A* takes the place of *B*, *B* the place of *C*, *C* the place of *D*, and *D* the place of *A*, it amounts to the same thing as reversing the armature cables or terminals, and the dynamo will refuse to generate.

[illegible] refers to a four-pole armature, but it is so connected that only two sets of brushes are needed, and these two brushes are shown in the position where it is most natural to expect to find them. Fig. 20, however, shows where, for reasons of accessibility, symmetry, and safety, the brush holders [illegible] generally found in practice.

FIG. 19

55. Field Coi[illegible] Failure to generate may be due to one or more [illegible] being incorrectly put on, or connected, so that they [illegible] each other. The only thing to do is to locate the [illegible] and reverse its connection. On a compound-w[illegible] dynamo, the reversal of a shunt-field coil will gener[illegible] the dynamo from picking up on open circuit, unless [illegible] dynamo has more than four coils; the more coils it has, [illegible] less effect has the reversal of a single coil. The rever[illegible] of a series coil is not felt until an attempt is made to [illegible] the machine; the voltage will not come up to where it [illegible] would for a given load and the brushes are apt to spark on account of the weakening of [illegible]

56. Low Speed.—[illegible] will pick up its field [illegible] with the field once established, [illegible] lower speed than that [illegible] The speed at which a series dyna[illegible] depends on the resistance of the external [illegible]

57. Among the causes of failure to generate not included [illegible] are faults in the [illegible] circuit, loose or open [illegible] the frame proper or between the pole pieces and [illegible] frame. Such imperfections also lower the maximum voltage of the dynamo. An armature core undersize or pole pieces bored out too large will cause the same trouble. There is one peculiar case on record where an extra armature was shipped from the factory and when put in the dynamo

refused to generate. The trouble was located in the armature core, which was found to be $\frac{5}{32}$ inch too small in diameter and an inch too short. The armature was given a running test before it left the factory, but it was run as a motor, and as no speed reading was taken, the mistake was not noticed. Occasionally orders become confused in the shipping department and the armature goes out with the wrong pulley; if the pulley is too large, the difference in speed will affect the picking up of the dynamo. Finally, it is possible to send out a 125-volt armature with 250-volt fields, or a 250-volt armature with 500-volt fields; in such a case it is only necessary to connect the fields in multiple to make the dynamo generate, if it should so happen that the voltage of the armature is the voltage wanted.

MOTOR FAILS TO START.

58. When a motor fails to start when the controlling switch is closed, any one of several things may be the matter. There may be an open circuit, a short circuit, a wrong connection, the power may be off the line, or the trouble may be purely mechanical. If the failure to start is due to an open circuit or to absence of power on the line, there will be no flash when the switch is closed and opened again. To tell if there is any power on the line, test with incandescent lamps or a voltmeter. If the fault is an open circuit, it may be found in any of the following places: Defective switch; broken wire or connection in the starting box; loose or open connection in some of the wiring; shellac on the commutator; a piece of foreign matter under one brush; brush stuck in the holder or no brush in it at all; brush springs up; fuse blown; some wire, apparently all right, broken inside of the insulation; or an open circuit in some part of the motor itself. Any of these sources of open circuit may be located with a magneto-bell or with a lamp or bell circuit. If the trouble is due to a short circuit, there will be a flash when the starting box is thrown off.

59. Among the more common sources of short circuit, are these: Short-circuited armature coils; short-circuited commutator; short-circuited field coils; field on a shunt or compound-wound motor connected so that the armature cuts out the field winding; carbonized brush yoke; brushes in the wrong position. If the armature coils or commutator are short-circuited, the machine may start and turn over part way and stop again. With a field coil short-circuited, the armature will start only under a heavy current, with accompanying sparking, and will acquire a high rate of speed.

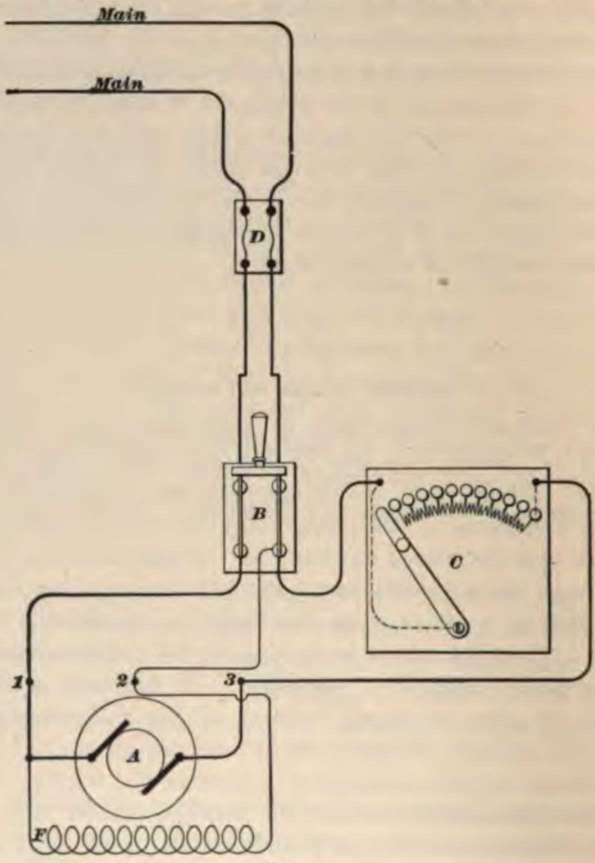

FIG. 21.

60. Fig. 21 shows the correct method of connecting a shunt motor with an ordinary starting box. Shunt motors are usually equipped with three terminals, *1*, *2*, *3*. Terminal *1* takes one armature lead and one end of the shunt field; terminal *2* the other end of the shunt; and terminal *3* the other end of the armature. By examining the figure it will be seen that *2* is connected ahead of the rheostat, so that as soon as the main switch *B* is thrown in, the shunt field is excited from the mains. Then when the handle of *C* is moved from the off position to the first point, the current that flows through the armature has a strong field to react on and the motor starts up with a good torque. Fig. 22 shows the motor wrongly connected. In this case, the wire running from post *2* is connected between the rheostat and the motor instead of being connected between the main switch and the rheostat; in fact, it is equivalent to connecting posts *1* and *2* together. The result is that the shunt field is connected to the armature terminals and no current will flow through it until the starting-box lever is moved over. As soon as the starting-box lever is moved, current flows through the armature, but very little flows through the field because the pressure across the field terminals is only equal to the drop in the armature. The result is that the field is very weak and the motor refuses to start until the starting lever is moved so far over that a very large current flows through the armature. The box becomes excessively hot, and if the fuses or circuit-breaker do not give way, there is danger of something being burned out.

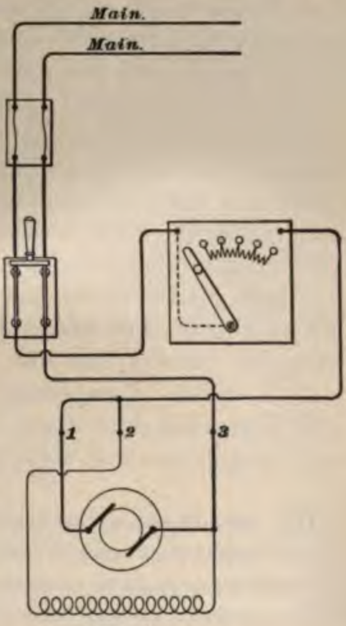

FIG. 22.

61. Wrong Motor Connections.—Wrong connections may be classed under two heads, *internal* and *external.* External wrong connections involve confusion of wires running to and from the motor, and are most likely to occur where a reverse switch must be used to change the direction of rotation of the armature. Such errors as getting an armature wire in where a field wire should go, or *vice versa*, come under this head. Where field and armature leads are of the same kind and are brought out through a closed motor frame, they should be felt out by hand, for this is where the confusion is most apt to take place. Wrong internal connections, as far as the man that assembles and sets up the motor is concerned, are confined to the field coils. If a motor has only two field coils and one of them is connected incorrectly, the motor will not start at all unless the starting current is so enormous that the armature itself magnetizes the field. If the motor has four coils and only one of them is incorrectly connected, the machine will start up under excessive current, but will spark badly and acquire a high rate of speed. Compound-wound motors with the series coils connected in to assist the shunt coils will not give the speed regulation that some classes of work require.

62. Mechanical Troubles.—Among the purely mechanical troubles that may interfere with the starting of a motor, the following may be mentioned: *Too much load; loose pole piece down on the core, or bearings worn until core is let down on the pole pieces; sprung armature shaft with the same result; hot box; tight belt; want of end play in the armature; some piece of foreign matter between the core and the pole piece, or between the pinion and the gear, if the motor is geared to its work.* In many cases, a motor can operate many more machines than it can start; it should be a rigidly enforced rule that all machine tools operated by the motor should have their shifters thrown over when the day's work is done. There is no excuse for an armature being let down on the pole pieces through wear in the bearings; they should be closely watched and close track kept of the time of last renewal. A loose pole piece not only restrains the armature mechanically, but it weakens the motor field and lessens the starting power. A sprung armature shaft is liable to occur at any time, and may be due to a suddenly imposed overload, a sudden reversal, or a hot box. A bent shaft is visible to the eye and causes the machine to make a noise. It should be taken out at once. Want of end play may be the fault of the maker or of the operator; on every shaft there are two shoulders that take the thrust of the bearings and limit the end play. Sometimes an armature will turn freely when cold, but when it becomes hot and expands it will bind on the collars. The end play must be limited or there will be knocking, so that if in renewing a set of bearings longer ones are put in than were taken out, the end-play problem is liable to arise. Bearings should always be turned to gauge. Belts should be long enough to allow of sag in the slack side, which should run on top. This improves the area of pulley contact and lessens the tension required to prevent slipping.

SPARKING.

63. Sparking at the brushes may be due to any of the following causes : *Too much load ; brushes improperly set ; commutator rough or eccentric ; brushes making poor contact ; dirty brushes or commutator ; too high speed ; sprung armature shaft ; low bearings ; worn commutator ; short-circuited or reversed armature coil ; high-resistance brush ; vibration ; belt slipping ; open-circuited armature ; weak field ; grounds.*

64. Too Much Load.—In this case the armature heats all over. The sparking may be lessened but not stopped by shifting the brushes ahead on a dynamo and back on a motor. If the machine is a motor, the speed will be low; if a dynamo, the voltage will be below the normal amount. In both cases the pulley is apt to get warm through slipping of the belt.

65. Brushes Improperly Set.—Brushes may be out of their proper position in either of two ways: they may be the right distance apart but too far one way or the other as a whole; this can, of course, be remedied by shifting the rocker-arm back and forth until the neutral point is found. The brushes may, as a whole, be central on the commutator, but too far apart or too close together. Such a fault must be remedied by adjusting the individual holders. On two-pole machines the two sets of brushes are placed diametrically opposite each other. On four-pole machines having two sets of brushes, the distance between the centers of the two sets should be just one-fourth of the circumference of the commutator. On four-pole machines having four brushes, they should set on the quarter; the best and quickest way to get this set in position is to place two sets at diametrically opposite points, the two remaining sets then go half way between them. In any case, for all commutator machines that are not special, the distance between the centers of adjacent sets of brushes should be the total number of commutator bars divided by the number of poles.

66. Commutator Rough or Eccentric.—A commutator will become rough either as a result of abuse or as a result of bad selection of the copper and mica of which it is made. If the mica is too thick or too hard, it will not wear as fast as the copper and will stand out in ridges. If too soft, it will eat out and make a furrow between bars that will catch carbon or copper dust and create local short circuits. An eccentric commutator acts like a bent shaft and may be the result of faulty workmanship or the result of a hard blow. In either case it must be turned true, but before doing it be certain that the commutator is at fault and not the shaft.

67. High or Low Bar.—A high or low commutator bar causes a clicking sound to be emitted whenever it passes under the brush. A high bar can often be removed with a file, but a low bar requires that the whole commutator be turned off.

68. Brushes Making Poor Contact.—Poor brush contact may be due to any one of several causes. The brush may be stuck in the holder; the temper may be out of the tension spring; the brush hammer may rest on the side of the holder and not on the brush; the brush may not fit the surface of the commutator; the holder may have shifted to the wrong angle. New brushes should be sandpapered to fit the commutator; the hammer should rest over the slot that guides the brush, so that when the brush wears it will follow it down. Tension springs should be paralleled by a conductor attached to the brush, so that the current will not flow through the springs and take the temper out of them.

69. Dirty Brushes or Commutator.—Carbon brushes are liable to give out paraffin when hot, which, getting on the commutator, insulates it in spots. The paraffin is also liable to mix with carbon dust and coat the brush with a non-conducting, sticky substance. A copper brush is apt to get clogged with oil, dust, and threads of waste (waste should never be used on a commutator). Brushes should be kept trimmed and cleaned. Dirty commutators, as a rule, are the result of using too soft a brush.

70. Too High a Speed.—A machine is apt to spark if its speed is too high, because it interferes with the commutation.

71. Sprung Armature Shaft.—A sprung armature shaft causes the commutator to wabble, giving very much the same symptoms as an eccentric commutator, and great care must be taken not to confuse a sprung shaft with an eccentric commutator.

72. Low Bearings.—On some types of machine, excessive wear in the bearings throws the armature far enough out of center to distort the field and cause sparking. Modern machines intended to stand fluctuating loads are so designed that there is no danger on this account.

73. Worn Commutator.—When a commutator wears down below a certain point, even if otherwise in good condition, it seems inclined to spark in spite of everything that can be done. It may be because the brushes then span more bars, because the bars become thinner as they wear away, or it may be because an error in the angle of the holder increases with the distance from the commutator. The effect is most noticeable on some street-railway motors where it is almost impossible to run together two motors whose commutators differ greatly in size. The brush holder should be kept as near the commutator as possible, as it not only enables the bars to be counted off more accurately, but it holds the brushes at a short leverage and prevents chattering.

74. Short-Circuited or Reversed Armature Coil. Either of these faults will cause a local current to flow, with the result that either a dynamo or a motor will require an unusual amount of power to run it even when unloaded. The reversed coil can be located by sending current through the coils one at a time and holding a compass over them. A short-circuited coil can be detected by holding a piece of iron up to the head of the armature while it is running; there will be a decided pulsation of the iron once each revolution. Also, a motor will run with a jerky motion especially noticeable at low speeds, and the voltmeter connected to a dynamo will fluctuate. Such a fault may be due to a cross in the coil itself or contact between two commutator bars. In either case, unless the cross is removed, the coil will burn out.

75. High-Resistance Brush.—Up to a certain point, high resistance in a carbon brush is a good feature, and that is why they are used. But it is possible to get the resistance so high that the brush will spark on account of its inability to carry the current at the contact surface. Such a brush will get very hot and will be slowly chewed off at the wearing end.

76. Vibration.—A shaky foundation will cause the whole machine to vibrate and will cause it to spark steadily, which fault can be remedied only by placing the machine upon a firmer foundation.

77. Belt Slipping.—A slipping belt will cause intermittent sparking because it subjects the machine to unusual variations in speed.

78. Open-Circuited Armature.—By an open-circuited armature is meant a break in one of the armature wires or its connections. Excessive current may burn off one of the wires or a bruise of some kind may nick a wire so that the normal load or less burns it off. A commutator may become loose and break off one or more leads. In any case there are two very characteristic symptoms of an open-circuited armature: a ball of fire runs around the commutator and the mica is eaten from between the bars to which the faulty coil is connected, the bars themselves become dark, pitted, and burned on the edges. Sometimes, on account of abuse, the armature throws solder and all the commutator connections become impaired. In such a case there are no actual open circuits, but there are a series of poor contacts that result in making the commutator rough and black, pitting the bars and eating the mica.

79. Weak Field.—A weak field may be due to a loose joint in the iron circuit, to a metallic short circuit in the field coils, to opposition of the field coils, or to the fact that heat has carbonized the insulation on the field coils so that the current short-circuits through it. Any of these influences decrease the number of lines of force that cross the armature, with the result that the starting power of the motor is decreased, and the speed and current are increased. On a dynamo, the E. M. F. and the ability to pick up are decreased.

80. Grounds.—On a metallic-return circuit, a single ground has no effect, but two grounds can so take place that the whole or any part of the field or armature may be cut out; such a pair of grounds is nothing more nor less than a short circuit and it falls under that head. On a ground-return circuit, a ground anywhere except in the armature has, as a rule, but one indication: there is a flash and the armature burns out.

OPERATION OF ALTERNATING-CURRENT MACHINERY.

ALTERNATORS.

81. The points given in regard to installing and handling the parts of direct-current machines hold good in regard to alternators. On account of the higher voltages used and the peculiar nature of the alternating current, abrasion of insulation through careless handling is apt to cause more serious trouble than on the lower voltage direct-current devices.

Alternating-current dynamos may be self-exciting or separately excited. As a rule, on account of the flexibility of control they are separately excited from a direct-current machine either coupled to the shaft of the alternator itself or run from an independent agent. In some cases the separate excitation is assisted by a current from the machine itself, this current being rectified by means of a commutator fixed on the shaft. The main and important advantage of separate excitation is that attendants are not called on to handle devices carrying the high voltage of the alternator in their ordinary duties of regulation.

Fluctuations of the voltage may be caused by slipping of the belt of the alternator or that of the exciter. This is one point in favor of directly connected machines with the exciter on the same shaft. All chance of fluctuation due to belt slipping on the exciter is then eliminated. As with any other separately excited machines, the direction of rotation of an alternator is immaterial as far as generation is concerned, but due regard must be had for the brushes on the rings and commutator if the machine has a rectifier.

Where there are two or more alternators to be run in multiple that are not excited from dynamos coupled to their own shafts, it is a good idea to excite them all from the same dynamo. The exciting plant should consist of at least two like units so wired that either can be used, which should be used alternately to insure that both are kept dried out and in good working order. Each alternator field can then be controlled by means of a resistance box in series with it. Alternator armatures are constructed along such simple and substantial lines that they give few of the petty troubles incidental to direct-current practice. Most of the trouble lies in the exciter and its circuit, so that the service of the alternator as a whole is influenced by all the troubles likely to arise in any direct-current circuit. If the exciter is out of order, so is the alternator; if the exciter breaks down, so does the alternator, unless provision is made for quickly throwing in a second exciter. If the exciter belt slips or its brushes spark or either the iron or copper part of the field circuit is impaired, the voltage of the alternator goes down.

Where the machine is alone on a circuit, it is started in the same way as any other isolated dynamo; it is brought up to speed, the field excited by closing the field circuit, and the voltage regulated with the field rheostat. To shut down, the same operations are gone through in the reverse order. Alternating-current machines have a great deal of self-induction; some of them have so much that even on a short circuit the current is not large enough to burn them out. On account of this great self-induction, a dynamo should not be unnecessarily subjected to violent variations in load. For example, if the circuit of an alternator is suddenly opened under full load, the high induced E. M. F. is liable to puncture the insulation and cause a breakdown.

82. Alternators in Parallel.—When alternators are operated in parallel with one another, they must all run at such speeds that their currents will be in step with one another; that is, the several currents must vary in unison with one another, all the currents coming to their maximum values at the same instant. When this condition exists, the machines are said to be *in synchronism;* and before one alternator is thrown in parallel with another, the attendant must make sure that the machine to be thrown in is in synchronism with those already in operation. This is usually indicated by synchronizing lamps or by a synchronizing voltmeter. Some synchronizing lamps are connected so that they go out when the machines are in step, while others are connected so that they light up. The attendant should always be sure as to just which way they are connected before he attempts to throw the machines in parallel. After the alternators are running together smoothly, their loads are adjusted by varying the field excitation.

ALTERNATING-CURRENT MOTORS.

83. Alternating-current motors call for the same general care as dynamos. Like all other dynamo machinery, they must be kept clean. Alternating-current machinery is generally operated at high pressure, and cleanliness is, therefore, absolutely necessary. In stations, it will pay to pipe compressed air to the machines and use a strong blast for blowing the dust and dirt out of the windings. Most of the motors in common use are of the synchronous, or induction, type.

84. Synchronous Motors.—These are the same in general construction as alternators. They are not intended to start up under load, but will run up to speed when connected to the line. In doing so they take a fairly large current, and in some cases, therefore, are brought up to synchronism by some outside source of power—as, for example, a small induction motor—before being connected to the line. Synchronous motors are separately excited and, in fact, are almost the same throughout as a separately excited alternator.

85. Induction Motors.—These motors are used for most work where the motor must frequently be started or stopped or where a good starting effort is required. In fact they are used for about the same kind of work as ordinary direct-current motors. There is nothing about them that requires any special care, that has not already been mentioned, after they are once installed. As a matter of fact, as they are inherently self-starting and have no commutator to give trouble, they require fewer precautions and less judgment on the part of the operator than direct-current machines. At starting there is a tendency to permit an excessive flow of current; this not only strains the machine electrically, but on account of the great armature reaction, which weakens the field, the starting power is also decreased. The starting current is, therefore, limited by means of resistance. This resistance takes either the form of a stationary rheostat placed in the circuit of the armature through collector rings, or it is in the form of a resistance placed within the body of the armature and operated either by means of a lever operating a switch concentric with the shaft or automatically by centrifugal force.

The direction of rotation of a two-phase motor can be reversed by reversing the leads of either phase; that of a three-phase motor by reversing any one of the phases, thereby reversing the magnetic rotation of the field.

86. Many of the smaller sizes of induction motors are started by simply throwing in the main switch, but with the larger sizes, this gives too great a rush of current. When a starting resistance is used, it should be cut out rather slowly in order to give the machine time to gain speed. On the other hand, the starting resistance should not be left in too long, or there will be danger of overheating the motor. Never use a starting resistance for the purpose of regulating the speed. This applies to all motors, direct or alternating. Starting resistances are designed to carry current for a short time only, and if current is allowed to flow through them continuously they will be burned out.

87. Another method of starting induction motors that is used considerably is by means of what is called a **starting compensator.** This is a device inserted between the motor field and the line, and serves to cut down the voltage applied to the motor at starting, thus preventing a rush of current.

Fig. 23 shows the connections for one of these starting compensators. *A* is a double-throw switch, *B*, *B*, *B* the line wires, and *C* the motor. In this figure the arrangement is shown for a three-phase motor. *E*, *E*, *E* are the coils wound on a laminated iron core similar to a transformer core. For a two-phase starter only two coils are necessary. These coils are provided with a number of taps, so that the compensator may be adjusted for different starting requirements. The switch is shown in the starting position, and by following out the connections it will be seen that one section of the coils is in series between the line and the motor field. One circuit, for instance, may be traced from *m* to *s* through *m–n–o–p–r–s*, when the switches are in the starting position. The E. M. F. developed in that portion of the coil between *p* and the adjustable contact *o* opposes, and hence decreases, the line voltage and allows the motor to start up gradually. After the motor is under headway, the switch is thrown up to the running position and one circuit may be traced through *m–n–r–s*. This cuts out the coils and connects the motor directly to the line. The operation of starting usually requires about 15 seconds for motors of moderate sizes. Always be sure that the starting device, no matter what kind it may be, is in circuit with the motor before throwing the main switch.

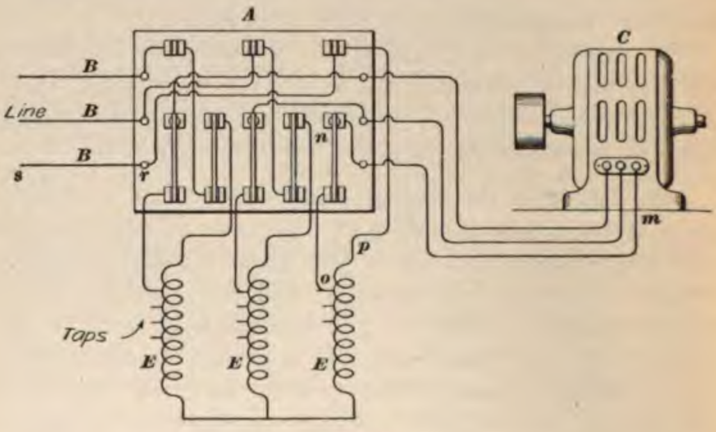

FIG. 23.

ROTARY TRANSFORMERS.

88. Rotary transformers, or converters, are used either to change alternating current to direct current or direct current to alternating. In most cases they are used to change alternating current to direct current, and when used to change from direct to alternating, they are often called **inverted rotaries.**

Rotary transformers combine the features of both direct-current machines and alternators, but on account of their peculiar nature a number of special points come up in connection with them that are not to be found with ordinary direct-current or alternating-current machines. The construction of the machine itself is very similar to that of a direct-current dynamo. The armature is provided with a winding in the same manner as the armature for a direct-current machine and this winding is connected to a commutator. The winding is also connected to collector rings, which serve to deliver alternating current to the machine. For example, when the rotary is used for changing alternating current to direct current, the alternating current is led into the armature winding by means of the collecting rings and is commuted, or changed, to a direct current, which is delivered to the lines attached to the brushes on the direct-current side. If direct current is supplied at the commutator, it flows through the windings and is changed to an alternating current, which is delivered from the collector rings. Rotary transformers when taking current from alternating-current lines run as synchronous motors, i. e., they run in step with the generator that drives them and their speed cannot change unless the speed of the generator changes. They may be run in parallel on either the direct-current or alternating-current sides.

89. Starting Rotary Transformers.—There are a number of different methods used for starting rotary transformers, and the one adopted will depend very largely on the conditions under which the machine is used. The following are some of the methods commonly used:

(*a*) *Starting from the Alternating-Current Side.*—When the machine is to be started from the alternating-current side, the fields are left unexcited and the armature is thrown into connection with the line through a starting resistance. The machine then starts and runs up to synchronism, but in so doing takes quite a large current from the line. The machine starts as an induction motor by virtue of the currents induced in the pole faces by the currents in the armature. After the rotary has come up to speed, the field switch is closed. Another method is to have a small induction motor connected to the shaft of the main machine. This motor is started from the line and runs the large machine up to synchronism. The large machine is then thrown in, and it can thus be started without using an excessive line current. As soon as the rotary is running, it excites its own fields from the direct-current side.

(*b*) *Starting from the Direct-Current Side.*—When a rotary is already in operation in a station and it is desired to start up another, the simplest way is to start up the rotary as a shunt-wound direct-current motor by first seeing that its fields are separately excited and then inserting a resistance in the armature circuit and gradually cutting it out as the machine comes up to speed, like any other direct-current motor. In many stations where storage batteries are used, the rotaries are started by using direct current from the batteries, because they furnish a source of direct current that is always available whether other rotaries are running or not. Another very good method for supplying direct current for starting or exciting purposes is to equip a station with a small direct-current dynamo directly connected to an induction motor. When starting a rotary as a direct-current shunt-wound motor, always be sure that the field is excited before connecting the armature, also see that under no circumstances is the field circuit broken while the machine is running as a direct-current motor. If the above happens, the machine will race, and cases are on record where rotary converters have been almost completely wrecked from this cause. Of course, where the machine is run from the alternating-current end, it runs in synchronism and the breaking of the field circuit will not result in racing. On the whole, however, starting with direct current is the preferable method.

(*c*) *Starting from the Alternator.*—This method of starting rotaries can only be used in comparatively few cases. It consists in connecting the rotary to the line and then starting the alternator in the distant station from which the rotary is operated. As the alternator comes up to speed, so does the rotary. This is a good method where it can be used, and especially where the rotaries are of large size.

(*d*) Another common method of starting is to have a small induction motor attached to an extension of the shaft of the rotary. This motor will start up readily when supplied with alternating current, and after it has brought the rotary up to speed it is cut out.

90. Hunting of Rotary Converters. — Sometimes rotary converters give a great deal of trouble due to what is known as *hunting*. The converter does not run uniformly, but develops a periodic variation in speed that causes wide fluctuations in the direct-current voltage. Excessive sparking is liable to result, and in some cases the effects have been almost as bad as a short circuit. This trouble has been particularly noticeable on converters made to operate at a fairly high frequency, say in the neighborhood of 60 cycles per second. Rotary converters are now generally operated on the lower frequencies, such as 40 or 25 cycles per second. When a machine hunts, the field shifts back and forth across the pole pieces, thus changing the position of the neutral field and giving rise to very bad sparking. The governor on the engine driving the alternator may be responsible for the hunting in the first place, or it may be caused by variations in the load, or by the influence of other machines on the same system. Its effects can be remedied to a considerable extent by putting heavy copper bridges between the pole tips and by surrounding the pole face with a heavy copper ring. If the field then shifts back and forth, it will set up heavy currents in the ring, or bridges, and these currents will tend to oppose any shifting of the field.

TESTING FOR FAULTS.

91. Many of the defects that are liable to arise in connection with dynamos and motors are, of course, apparent from a mere inspection of the machine. Other defects, such as short-circuited or open-circuited field coils, short-circuited or open-circuited armature coils, etc., must be located by making tests. Many of these tests have already been referred to, and the following is intended to show how they are carried out. For tests of this kind Weston or similar instruments are most convenient if they have the proper range for the work in hand. For measuring resistances, the *drop-of-potential method* is generally most easily applied. This method consists in sending a known current through the resistance to be measured and noting the pressure between the terminals of the resistance; in other words, noting the pressure required to force the known current through the unknown resistance. The resistance may then be determined at once from Ohm's law, because $C = \frac{E}{R}$, or $R = \frac{E}{C}$. If the resistance to be measured is very low, as, for example, an armature coil, the voltmeter must be capable of reading low and a millivoltmeter (one reading to thousandths of a volt) will be best suited to the work. Of course, a good Wheatstone bridge may also be used for measuring resistances, but it is generally not as convenient to use around a station as the drop-of-potential method.

92. Testing for Open-Circuited Field Coils.—If a machine does not pick up, it may be due to the absence of residual magnetism. If any residual magnetism is present, a voltmeter connected across the brushes will give a small ction when the machine is run up to full speed, so that point can easily be determined before a test is made for oken field coil. Examination of the connections between various coils will show if they are defective or loose; te frequently the wire in the leads from the spools omes broken at the point where the leads leave the spool, hile the insulation remains intact, so that the break does t show. This may be detected by "wiggling" the leads. If the break is inside the winding of one of the coils, it can nly be detected by testing each coil separately to see if its rcuit is complete. This may be done with a Wheatstone bridge or with a few cells of battery and a galvanometer. A low-reading Weston voltmeter makes a good galvanometer to use for this purpose.

If the current from another dynamo can be obtained, the faulty spool may be detected by connecting the terminals of the field circuit to the terminals of the circuit of the other machine; no current will flow through if the circuit is broken, but if a voltmeter is connected across each single field coil in succession, it will show *no deflection* if the coil is continuous, because both poles of the voltmeter will be connected to the *same* side of the dynamo circuit. If the coil has a break in it, one of its terminals will be connected to one side of the circuit and the other to the other side, so that a voltmeter connected between these terminals will show the full E. M. F. of that circuit. Consequently, when the voltmeter is connected across a spool and shows a considerable deflection, that spool has an open circuit which must be repaired before the dynamo can operate.

This method of testing is represented by the diagram, Fig. 24; *1*, *2*, *3*, and *4* represent the field coils of a four-pole dynamo, there being a break in coil *2* at *B*. The terminals *a* and *e* of the field winding are connected to the + and − terminals of a "live" circuit; that is, a circuit connected to a dynamo in operation. It will be seen that terminals *a* and *b* of coil *1* are both connected to the + side of the circuit, and as there is no current flowing through the circuit, there is no difference of potential between *a* a therefore, a voltmeter connected to *a* and *b*, as at *V*, will show no deflection. But terminal *c* of coil *2* is connected to the − side of the circuit; so a voltmeter connected to *b* and *c*, as at V_1, will show a deflection, and, in fact, will indicate the difference of potential between *a* and *e*.

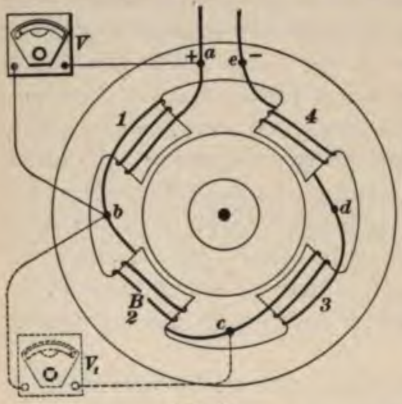

FIG. 24.

The above test may be roughly made with a bit of wire long enough to span from terminal to terminal of a coil. If one end of the wire is touched on *a*, for instance, and the other on *b*, it will not affect the circuit; but if it is touched on the terminals of the coil in which the break is located, the field circuit will be completed through the bit of wire, and a spark will occur when the wire is taken away. The wire should not be allowed to span more than one coil at a time, otherwise it may short-circuit so much of the field winding that too great a current will flow.

93. Short-Circuited Field Coil.—It is evident that if the windings of a field coil become short-circuited, either by wires coming in contact or by the insulation becoming carbonized, the defective coil will show a much lower resistance than it should. The drop of potential across the various field coils should be about the same for each coil, so that if one coil shows a much lower drop than the others, it indicates a short circuit of some kind.

94. Test for Grounds Between Winding and Frame. After the machine has thoroughly warmed up, it should be tested for "grounds," or connections between the winding and the frame or armature core. This may best be done with a good high-resistance voltmeter as follows: While the machine is running, connect one terminal of the voltmeter to one terminal of the dynamo, and the other terminal of the voltmeter to the frame of the machine, as represented in Fig. 25, where T and T_1 are the terminals of the dynamo, and V and V_1 two positions of the voltmeter, connected as described above.

If in either position the voltmeter is deflected, it indicates that the field winding is grounded somewhere near the *other* terminal of the dynamo; that is, if the voltmeter at V shows a deflection, the machine is grounded near the

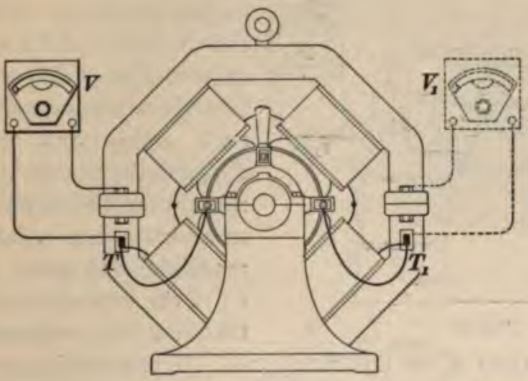

FIG. 25.

terminal T_1, and *vice versa*. If the needle shows a deflection in *both* positions, but seems to vibrate or tremble, the armature or commutator is probably grounded. If in either case the deflection does not amount to more than about $\frac{1}{20}$ the total E. M. F. of the machine, the ground is not serious, but if the deflection is much more than this, the windings should be examined separately, the ground located, and, if possible, removed.

95. To locate the ground, if thought to be in the field coils, each coil should be disconnected from its neighbor (with the machine shut down, of course) and "tested out" by connecting one terminal of another dynamo (or "live" circuit) to the frame of the machine, care being taken to make a good contact with some bright surface, such as the end of the shaft or a bolt head, and the other to a terminal of the coil to be tested, through a voltmeter, as represented in Fig. 26.

Here *C* and C_1 represent the terminals of a "live" circuit, which should have a difference of potential between them about equal to the E. M. F. of the machine when it is in operation, but not greater than the capacity of the voltmeter will allow of measuring. *T* and T_1 represent the terminals of the dynamo, as before, and *t* and t_1, the terminals of the field coils, which have been disconnected from each other and from the dynamo terminals. One terminal *C* of the circuit is connected to the frame of the machine; the other terminal C_1 of the circuit is connected through the voltmeter *V* to the terminal t_1 of the field coil. If that coil is grounded, the voltmeter will show a deflection about equal to the E. M. F. of the circuit $C\ C_1$, but if the insulation is intact, it will show little or no deflection. The wire connecting the voltmeter with the terminal t_1 may be connected in succession to the terminal of the other coil, or coils, and to the commutator; any grounded coil of the field or armature winding will be shown by a considerable deflection of the voltmeter needle.

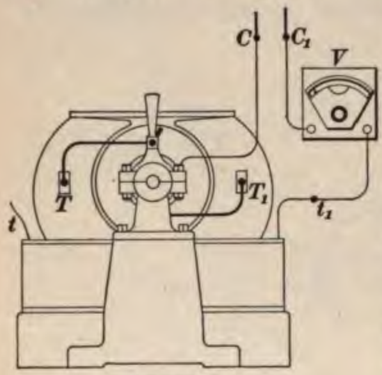

FIG. 26.

96. If the machine tests out clear of grounds, it should be shut down after the proper length of time and the various parts of the machine felt over to locate any excessive heating. If accurate results are wanted, thermometers should be used, placing the bulb on the various parts (armature, field coils, etc.) and covering it with a wad of waste or rags. They should be looked at from time to time until it is seen that the mercury no longer rises, when the point to which it has risen should be noted. A thermometer hung on the wall of the room will give the temperature of the air, and the difference between the air temperature and that of the various parts of the machine should not exceed the prescribed limit.

97. Test for Defects in Armature (Bar-to-Bar Test).—Faults in armatures may best be located by what is known as a **bar-to-bar test.** This consists briefly in sending a current through the armature (in at one side of the commutator and out at the opposite side) and measuring the drop between adjacent bars all around the commutator. If the armature has no faults, the drop from bar to bar should be the same for all the bars. The connections for this test are shown in Fig. 27. *E* is the line from which the current for testing is obtained and *L B* a lamp bank by means of which the current flowing through the armature may be adjusted. Connection is made with the commutator at two opposite points *A*, *B*. A contact piece, or crab, *C* is provided with two spring contacts that are spaced so as to rest on adjacent bars. These contacts are connected to a galvanometer, or

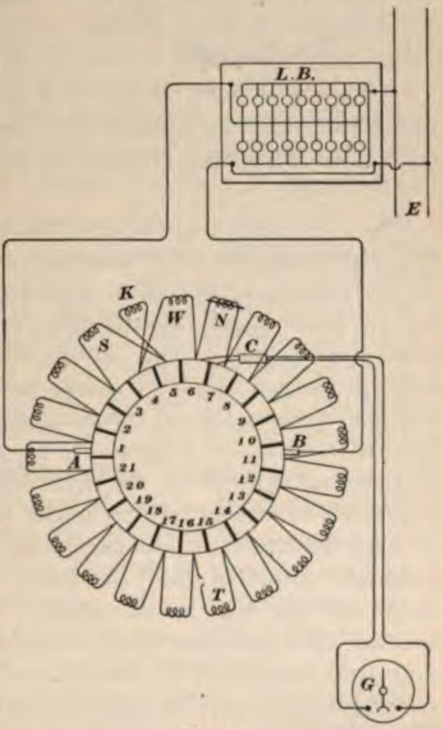

FIG. 27.

millivoltmeter, E. For the sake of illustrating the way in which the bar-to-bar test will indicate various kinds of faults, we will suppose that in coil F there is a short circuit, that the commutator leads of coils S, K, and W have been mixed, as shown, and that there is an open circuit in coil T. Current will flow through the top coils from A to B, but not through the bottom coils on account of the open circuit at T. Terminals A, B may be clamped permanently in place by means of a wooden clamp, or a strap such as shown in Fig. 29 may be used.

FIG. [illegible]

98. It is evident that the deflection of the galvanometer will depend on the difference of potential between the bars. [illegible] practically the same deflection [illegible] commutator, no matter on [illegible]. The test is carried out as [illegible] galvanometer, or [illegible] deflection when C is in contact [illegible] good coils. The amount [illegible] will depend on the [illegible]. If the armature is [illegible] small current will give [illegible] of low resistance, a [illegible]. The operator runs over several bars and gets what is called the standard deflection and then compares all the other deflections with this. In case he should start on the damaged part, he will find when he comes to the good coils a difference in deflection.

If the contact rests on bars [illegible], it is easily seen that a deflection much larger (about double) than the standard will be obtained, because two coils are connected between *3* and *4* in place of only one. When on *4* and *5*, the deflection of the voltmeter, or galvanometer, would reverse, because the leads from *K*, *S*, and *W* are crossed. The deflection would not be greater than the standard, because only one coil is connected between *4* and *5*. Between *5* and *6* a large deflection will be obtained for the same reason that a large one was obtained between *3* and *4*. Between *6* and *7* little or no deflection will be obtained, because coil *7* is here represented as being short-circuited and, hence, there will be little or no drop through it. As *C* is moved around on the lower side, no deflection will be obtained until bars *15* and *16* are bridged. There will then be a violent throw of the needle, because the voltmeter will be connected to *A* and *B* through the intervening coils. When *C* moves on to *16* and *17*, there will again be no deflection, thus locating the break in coil *T*. As a temporary remedy for this, bars *15* and *16* may be connected together by a "jumper" or piece of short wire.

99. If any of the coils have poor or loose connections with the commutator bars, the effect will be the same as if the coil had a higher resistance than it should and, hence, the galvanometer deflection will be above the normal. In practice, after one has become used to this test, faults may be located easily and rapidly. It is best to have two persons, one to move *C* and the other to watch the deflections of *G*.

100. Locating Short-Circuited Armature Coils. Where there are a large number of armatures to be tested, as, for example, in street-railway repair shops, an arrangement similar to that shown in Fig. 29 is very convenient for locating short-circuited coils. *A* is a laminated iron core with the polar faces *b*, *b* (in this case arranged for four-pole armatures). This core is wound with a coil *c* that is connected to a source of alternating current. The core is built up to a length *d*, about the same as the length of the armature core. The core *A* is lowered on to the armature, and when an alternating current is sent through *c* an alternating magnetization is set up through the armature coils.

pine plank, with tongued-and-grooved joints that should be leaded to make them tight, the whole being held together by cross bolts, as represented in the figure.

Two iron rods *R*, *R* are placed across the top of the tank, to which are attached the terminals of the dynamo circuit, as represented at *W*, *W*. From these rods two iron plates *P*, *P* are hung, which should have about 3½ or 4 square feet of surface (on one side) below the water level. These plates may be made of a couple of pieces of old boiler plate or heavy (¼-inch or thicker) sheet iron, cut with two projecting lugs on the top, which are bent into hooks by which the plates are hung from the rods *R*, *R*. Cast iron will do equally well; two old ash-pit doors, for example, will make very good plates, the rods being passed through the holes for the hinge pins. When ready for use, the tank should be filled with water, and from 5 to 20 pounds of rock salt or washing soda added to reduce the resistance to the required figure, as water alone will give altogether too high a resistance.

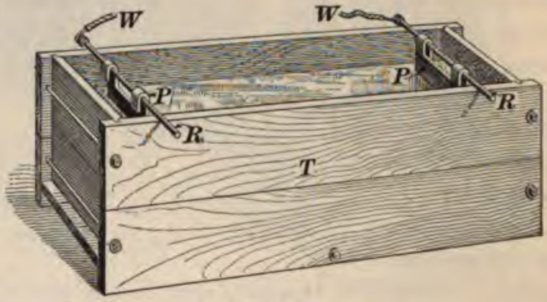

FIG. 31.

HEAT AND STEAM.

HEAT.

NATURE OF HEAT.

1. All modern scientists and investigators agree that **heat** is a *form of energy*. It is conceived to be a motion of the molecules composing matter. All matter is composed of molecules, which, according to the generally accepted theory, are not in a state of rest, but are moving or vibrating back and forth with a greater or less velocity. It is this movement of the molecules that is generally believed to cause the sensations of warmth and cold; if the motion is slow, the body feels cold; whereas, if the motion is rapid, the body feels warm. Since a body in motion has kinetic energy and since the molecules composing matter are supposed to be in motion, each molecule possesses kinetic energy; hence, we can conceive heat to be a form of energy.

2. Temperature is a term used to indicate how hot or cold a body is; i. e., to indicate the velocity of the vibration of the molecules of a body. A body having a high temperature is said to be hot; a body having a low temperature is said to be cold. When a body, as, for example, an iron bar, receives heat from any source, its temperature rises; on the other hand, when a body loses heat, its temperature falls.

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The temperature is *not* a measure of the *quantity* of heat a body possesses. *Temperature* may be considered to be a measure of the velocity with which the molecules of a body vibrate to and fro, while the *quantity of heat* may be considered to be the kinetic energy of the molecules composing the body. A small iron rod may be heated to whiteness and yet possess a very small quantity of heat. Its temperature is very high, but this simply indicates that the molecules of the rod are vibrating with an extremely high velocity. An iron ball 1 foot in diameter and an iron ball 1 inch in diameter may have exactly the same *temperature*, but the larger ball would have by far the greater quantity of heat.

3. The Thermometer.—Temperature is measured by an instrument called the **thermometer,** which is so familiar as to scarcely need description. It consists of a thin glass tube, at one end of which is a bulb filled with mercury. Upon being heated, the mercury expands in proportion to the rise of temperature. Thermometers are graduated in different ways. In the Fahrenheit thermometer, which is the one generally used in this country, the point where the mercury stands when the instrument is placed in melting ice is marked 32°. The point indicated by the mercury when the thermometer is placed in water boiling in the open air at the level of the sea is marked 212°. The tube between these two points is divided into 180 equal parts, called **degrees.**

4. Effects of Heat.—Suppose we take a vessel filled with some substance, say water. Let the vessel be a cylinder fitted with a piston, as shown in Fig. 1. The water is, say, at the freezing point, and the millions of molecules composing the water are moving to and fro with a comparatively small velocity. Place the vessel over a fire or furnace. Heat is communicated to the molecules of water, and they begin to move faster and faster. That is, their kinetic energy increases, and if a thermometer is inserted in the vessel, it will be found that the temperature of the water rises. Consequently, one effect of heat is to raise the temperature of the body to which it is applied. But, after reaching a certain temperature, the molecules of the water not only move faster, but they move farther from each other, and their paths are longer. It is plain that if the molecules are farther apart than they were originally, the whole body of them must take up more space. In other words, after reaching a certain temperature, the water expands as heat is added. Hence, another effect of heat is to cause bodies to expand. Common examples of the expansion of bodies by heat are seen in the setting of tires, the expansion of the rails of a railway in summer, etc.

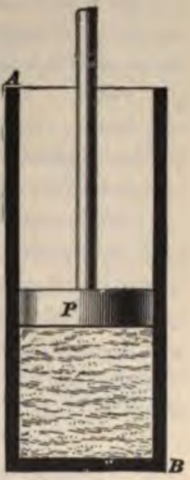

FIG. 1.

5. The heat supplied to the vessel of water has so far done three things: (1) It has raised the temperature of the water and thus has increased the kinetic energy of the molecules. Let the amount of heat expended for this purpose be denoted by S. (2) A certain quantity of heat has been used in expanding the water, that is, in pushing the molecules farther apart against the force of cohesion. Denote the amount of heat so expended by I. (3) Since the water expands, it must raise the piston P against the pressure of the atmosphere, and consequently more heat must be used to expand the water than would be required if there were no pressure on the upper side of the piston. Call this extra quantity of heat W.

If we denote by Q the total quantity of heat given to the vessel of water, we have

$$Q = S + I + W.$$

Ordinarily, the greater part of the heat given to a body is spent in raising its temperature, and but little is used in expanding the body. That is, the quantity S is nearly equal to the quantity Q, while the quantities I and W are extremely small.

6. Suppose that the piston in Fig. 1 is removed from the cylinder, so that the water will be in contact with the atmosphere, and that a thermometer is inserted. As the water becomes more and more heated, the temperature indicated by the thermometer will rise until it reaches 212°. So far, most of the heat has been used to raise the temperature of the water. But now, no matter how much heat is added to the water, the mercury stands at 212°, and cannot be made to rise higher. This is the reason: When the temperature reaches 212° the molecules of water have been set into such rapid motion that the force of cohesion is no longer able to hold them and they tend to separate. In other words, the water changes to a gas (steam), and all the heat is being used to effect this change. The temperature of the steam will remain at 212° until all water is changed to steam; then, if more heat is applied, the temperature of the steam will begin to rise.

7. Again, suppose we take a block of ice at a temperature of, say, 14° and heat it. If a thermometer is placed in contact with the ice, the mercury will rise until it reaches 32° and will then remain stationary. As soon as this temperature is reached, the ice begins to melt or change to water, and the heat, instead of raising the temperature farther, is all used to effect this change of state. Here, then, is another effect produced by heat. It will change a solid to a liquid or a liquid to a gas.

8. Summary.—By a study of the results of applying heat to the substances that have just been considered, we see that the effects of heat most commonly observed are: (1) It increases the rate of motion of the molecules, an effect that is indicated by an increase in temperature. (2) It increases the lengths of the paths of, and the distance between, the molecules, thus causing the body to expand and fill a greater space. (3) It overcomes the attractive forces that tend to hold the molecules of a substance together, and thus changes it from a solid to a liquid or from a liquid to a gas, according to the state it was in when the heat was applied.

The second statement of the summary, while generally true, is subject to exceptions, the most notable one of which is water, which in rising from a temperature of 32° Fahrenheit to a temperature of 39.2° contracts instead of expands.

9. Latent Heat.—The heat that is expended in changing a body from the solid to the liquid state or from the liquid to the gaseous state is called **latent heat.** The portion of the heat applied that raises temperature and that, therefore, affects the thermometer is sometimes called **sensible heat.**

10. Measurement of Heat.—Since heat is not a substance, it cannot be measured directly in pounds or quarts, but, like force, it may be measured by the effects it produces. Suppose that a certain quantity of heat raises the temperature of 1 pound of water from 52° to 53° Fahrenheit. It will take the same quantity of heat to raise that pound from 53° to 54°, and therefore it will take nearly double that quantity to raise the temperature of 1 pound of water from 52° to 54°. The unit quantity of heat is the quantity required to raise the temperature of a pound of water from 62° to 63°. This unit is called the **British thermal unit,** and is commonly abbreviated to B. T. U.

11. For temperatures above 63°, it takes slightly more than 1 B. T. U. to produce a change of 1 degree in 1 pound of water—the difference increasing the farther the temperature is from 63°. For temperatures below 62°, it takes slightly less than 1 B. T. U. to produce a change of 1 degree in 1 pound of water; and, as before, the difference is greater the farther the temperature is from 62°. Thus it will take more heat to raise the temperature of 1 pound of water from 75° to 76° than it will to raise it from 74° to 75°. Likewise, it will take less heat to raise the temperature of 1 pound of water from 42° to 43° than to raise it from 43° to

44°. However, the difference between the actual B. T. U., as defined above, and the quantity of heat required to change the temperature of 1 pound of water 1 degree for any other temperature is so small that, for all ordinary purposes, it may be assumed that it takes 1 B. T. U. to produce a change of 1 degree in the temperature of 1 pound of water for all temperatures that we are likely to meet in practice.

12. Relation Between Heat and Work.—Suppose that, in the experiment shown in Fig. 1, the piston had been allowed to remain in the cylinder while the water was being changed to steam. Steam at 212° occupies nearly 1,700 times the space that the water originally occupied. Hence, the piston would be lifted in the cylinder to give room for the steam that was being formed. But to raise the piston requires work. Here, then, is an example of work being performed by heat. On the other hand, work will produce heat. If two blocks of wood are rubbed briskly together, they will become warm, and may even ignite. The work done in overcoming friction causes the journals and bearings of fast-running machines to heat. A small iron rod may be heated to redness by pounding it on an anvil.

13. Since work may be changed into heat and heat into work, it seems probable that there is some fixed ratio between the unit of heat (B. T. U.) and the unit of work, the foot-pound. By a series of careful experiments, Dr. Joule, of England, discovered this ratio.

He found that 1 B. T. U. is equivalent to 772 foot-pounds; later and more careful experiments show that 778 foot-pounds is more nearly correct. This number, 778 foot-pounds, is called the **mechanical equivalent** of 1 B. T. U.

We have, then, the following important law: *Heat may be changed to work or work to heat; 778 foot-pounds of work are required to produce 1 B. T. U.; and, conversely, the expenditure of 1 B. T. U. produces 778 foot-pounds of work.*

EXAMPLE 1.—The burning of 1 pound of coal gives out sufficient heat to raise 14,000 pounds of water from 62° to 63°. If all this heat is utilized, how high will it lift a weight of 700 pounds?

SOLUTION.—Since 1 B. T. U. raises the temperature of 1 pound of water from 62° to 63°, it requires 14,000 B. T. U. to raise 14,000 pounds of water from 62° to 63°; hence, the burning of 1 pound of coal gives out 14,000 B. T. U. One B. T. U. is equivalent to 778 foot-pounds; hence, 14,000 B. T. U. are equivalent to $14,000 \times 778 = 10,892,000$ foot-pounds. Then, the height to which the weight can be raised is $10,892,000 \div 700 = 15,560$ ft. Ans.

EXAMPLE 2.—A cannon ball weighing 60 pounds moves with a velocity of 1,300 feet per second. Suppose the ball were suddenly stopped and all its kinetic energy changed into heat, how many B. T. U. would be developed? If all this heat were applied to 100 pounds of water at a temperature of 60°, to what temperature would the water be raised?

SOLUTION.—The kinetic energy of the cannon ball is $\frac{W v^2}{64.32} = \frac{60 \times 1,300^2}{64.32} = 1,576,492$ foot-pounds. But 778 foot-pounds = 1 B. T. U. Therefore, the number of B. T. U. developed is $1,576,492 \div 778 = 2,026.3$ B. T. U. Since 1 B. T. U. raises the temperature of 1 pound of water 1 degree, it will take 100 B. T. U. to raise 100 pounds of water 1 degree. Hence, 2,026.3 B. T. U. will raise 100 pounds of water $2,026.3 \div 100 = 20.26$ degrees, and the final temperature of the water will be $60° + 20.26° = 80.26°$. Ans.

14. Specific Heat.—One B. T. U. raises the temperature of 1 pound of water 1 degree; will it have the same effect on a pound of mercury? Heat two 1-pound iron balls to the temperature of boiling water, 212°; having now the same weights and temperatures, each ball has the same quantity of heat. Place one of these balls in a vessel, into which slowly pour enough water having a temperature of 60° so that the iron will be cooled to 70° while the water is heated to the same temperature. Now place the other hot ball in another vessel, into which pour mercury having a temperature of 60°, until the iron and mercury reach a common temperature of 70°. In each case the hot ball will have been cooled from 212° to 70°, and therefore each will have given up the same quantity of heat. When, however, we consider the effects produced by the heat, we find that what has been given off by one ball has raised nearly 1.62 pounds of water 10 degrees; that given off by the other ball, which, it will be remembered, is the same amount as in the first case, has raised 48.5 pounds of mercury (or nearly 30 times more mercury than water) the same number of degrees. It is plain, therefore, that to raise 1 pound of mercury from 62° to 63° requires $\frac{1}{30}$ the heat necessary to raise 1 pound of water from 62° to 63°. Hence, we say the specific heat of the mercury is $\frac{1}{30}$ or .0333.

15. *The* **specific heat** *of a body is the ratio between the quantity of heat required to warm that body 1 degree and the quantity of heat required to warm an equal weight of water 1 degree.*

Example 1.—It is found that to raise the temperature of 20 pounds of iron from 62° to 63° requires 2.276 B. T. U. What is the specific heat of iron?

Solution.—To raise 20 pounds of water from 62° to 63° requires 20 B. T. U. The specific heat of the iron is, according to the above definition, the ratio between the quantities of heat required to raise the temperature of the iron and the water, respectively, through 1 degree, that is, it is the ratio $2.276 : 20 = 2.276 \div 20 = .1138$. Ans.

Example 2.—The specific heat of silver is .057. How many B. T. U. are required to raise 22 pounds of silver from 50° to 60°?

Solution.—To raise the temperature of 1 pound of water 1 degree requires 1 B. T. U. Since the specific heat of silver is .057, only .057 B. T. U. is required to raise 1 pound of silver 1 degree. Hence, to raise 22 pounds of silver 10 degrees must require $.057 \times 22 \times 10 = 12.54$ B. T. U. Ans.

Rule 1.—*To find the number of B. T. U. required to raise the temperature of a body a given number of degrees, multiply the specific heat of the body by its weight in pounds and by the number of degrees.*

Denote the number of B. T. U. required by U; the specific heat by c; the weight by W; and let t and t_1, respectively, be the temperatures before and after the heat is applied.

Then, $$U = c\,W\,(t_1 - t).$$

The specific heat of some of the more common substances is given in the following table :

SPECIFIC HEAT OF SUBSTANCES.

Substance.	Specific Heat.	Substance.	Specific Heat.
Water	1.0000	Ice	.5040
Sulphur	.2026	Steam (superheated)	.4805
Iron	.1138	Air	.2375
Copper	.0951	Oxygen	.2175
Silver	.0570	Hydrogen	3.4090
Tin	.0562	Carbon monoxide	.2479
Mercury	.0333	Carbon dioxide	.2170
Lead	.0314	Nitrogen	.2438

16. Latent Heat of Fusion.—This term is applied to the quantity of heat required to change a pound of a given substance from the solid to the liquid state. The only case of interest to the engineer is the heat required to change 1 pound of ice to water. Careful experiments have shown that about 144 B. T. U. are required to change 1 pound of ice at 32° to water at 32°. Hence, the latent heat of water is 144 B. T. U.

17. The **latent heat of steam** is the quantity of heat required to change 1 pound of water at a given temperature into steam at the same temperature. Experiment has shown that at a temperature of 212° this quantity of heat is about 966 B. T. U. This means that the heat required to change 1 pound of water at 212° to steam is 966 times as great as the heat required to raise the temperature of a pound of water from 62° to 63°. The latent heat of steam is different for different temperatures, as will be seen by referring to the Steam Tables.

EXAMPLE.—How many B. T. U. are required to change 5 pounds of ice at 15° into steam at 212°?

SOLUTION.—To raise the temperature of the ice from 15° to 32° (the melting temperature) requires, according to rule **1**,

$$.504 \times 5 \times (32 - 15) = 42.84 \text{ B. T. U.}$$

To change the ice to water requires 144 B. T. U. for each pound, or $144 \times 5 = 720$ B. T. U. To raise the water from 32° to 212° requires, from rule **1**,

$$1 \times 5 \times (212 - 32) = 5 \times 180 = 900 \text{ B. T. U.}$$

Finally, to change the water to steam requires 966 B. T. U. per pound, or $966 \times 5 = 4{,}830$ B. T. U. Therefore, in all, $42.84 + 720 + 900 + 4{,}830 = 6{,}492.84$ B. T. U. are required. Ans.

Expressed in foot-pounds, the work required to effect the above change would be $6{,}492.84 \times 778 = 5{,}051{,}429.5$ foot-pounds, or work enough to lift a weight of 1,000 pounds nearly a mile.

18. Since a pound of ice requires 144 B. T. U. to change it to water, it follows that when a pound of water at 32° changes to ice (freezes), 144 B. T. U. are given out in the process. Similarly, the condensation of a pound of steam into water at 212° liberates 966 B. T. U. This principle is applied in heating buildings by steam. The steam passes through the radiators and condenses. The latent heat thus set free warms the building.

19. Temperatures of Mixtures.—It is often desirable to calculate the final temperature of a mixture of different substances at different temperatures. The following law is to be observed in such cases: *The quantity of heat in a mixture is the same as the quantity of heat contained in the substances before being combined.* If two substances of different temperatures are placed together, they both finally attain the same temperature; the heat lost by one in coming from a higher to a lower temperature is gained by the other in passing from a lower to a higher temperature.

Rule 2.—*To find the temperature of a mixture of several substances, multiply together the weight, specific heat, and temperature of each substance separately and add the products. Next multiply together the weight and specific heat of each of the substances separately and add these products. Divide the former sum by the latter. The result will be the temperature of the mixture.*

EXAMPLE.— 15 pounds of water at 42° and 30 pounds of mercury at 70° are placed in the same vessel, and a ball of lead weighing 19 pounds and having a temperature of 110° is immersed in the mixture. What is the final temperature of the contents?

SOLUTION.—Applying rule 2, the product of the weight, specific heat, and temperature of the water is $15 \times 1 \times 42 = 630$; of the mercury, $30 \times .0333 \times 70 = 69.93$; of the lead, $19 \times .0314 \times 110 = 65.626$; and the sum is $630 + 69.93 + 65.626 = 765.556$.

The product of the weight and specific heat of the water is $15 \times 1 = 15$; of the mercury, $30 \times .0333 = .999$; of the lead, $19 \times .0314 = .5966$; and the sum is $15 + .999 + .5966 = 16.5956$. Then, the temperature of the mixture is $765.556 \div 16.5956 = 46.13°$. Ans.

20. A particularly important case is the mixture of steam and water. Let W and t_1 represent the weight and temperature of the steam and let w and t represent the weight and temperature of the water. Let T represent the final temperature of the mixture and L the latent heat of the steam at the given temperature. Then, the temperature of a mixture of steam and water may be found by means of the following rule:

Rule 3.—*When steam and water are mixed, the steam condenses. To find the final temperature of the mixture, add the latent heat and the temperature of the steam and multiply this sum by the weight of the steam. To this product add the product of the weight and temperature of the water and divide the sum so obtained by the sum of the weights of the steam and water. The quotient will be the temperature of the mixture.*

Or,
$$T = \frac{W(L + t_1) + w\,t}{W + w}.$$

In the case of a mixture of water and steam, it is to be observed that the temperature of the mixture can never be more than the temperature of the steam, no matter whether the mixture takes place in an open or a closed vessel. The reason for this is to be found in the fact that after the steam has heated the water to its own temperature, there can be no further giving up of heat, since in order that heat may pass from one body to another, there must be a difference in the temperature of the two bodies, the heat passing from the hotter body to the colder one. The only way in which heat can be made to pass from a colder to a hotter body or from one body to another one at an equal temperaature is by the expenditure of work; but as this condition does not ordinarily exist in the case of steam and water being mixed, it follows that the temperature of the mixture can never exceed that of the steam.

Whenever rule **3** gives a temperature in excess of that of the steam, it is an indication that the quantity of water mixed with the steam is not sufficient to condense all the steam, and consequently the given temperature of the steam (in case of a closed vessel) or the temperature of the steam corresponding to the existing atmospheric pressure (in case of an open vessel) should be substituted for the temperature given by rule **3.**

EXAMPLE.—If 8 pounds of steam at 212° are run into a barrel containing 300 pounds of water at 43°, what will be the final temperature?

SOLUTION.—The weight of the steam $W = 8$ pounds; the latent heat $L = 966$ B. T. U.; the temperature $t_1 = 212°$. The weight of the water $w = 300$ pounds; the temperature $t = 43°$. Hence, from rule **3,** the final temperature is

$$\frac{8 \times (966 + 212) + 300 \times 43}{8 + 300} = 72\tfrac{1}{2}°. \quad \text{Ans.}$$

EXAMPLES FOR PRACTICE.

1. A body weighing 143 pounds falls 62 feet. If the energy of the body at the end of the fall is changed into heat, how many B. T. U. will be developed? Ans. 11.39 B. T. U.

2. An expenditure of 210 B. T. U. per minute will develop how many horsepower? Ans. 4.95 H. P.

3. If $\frac{1}{7}$ the total heat in the coal is used in doing work, how many pounds of coal must be burned per hour to run a 40-horsepower engine? Each pound of the coal gives out 13,500 B. T. U. Ans. 52.8 lb.

4. A bar of iron weighing 20 pounds and having a temperature of 350° is plunged into a tank containing 130 pounds of water at 55°. To what temperature will the water be raised? Ans. 60°.

5. How many pounds of ice at 32° can be melted by 3 pounds of steam at 212°? Ans. 23.875 lb.

SUGGESTION.—Each pound of ice requires 144 B. T. U. to melt it; each pound of steam in changing to water at 32° gives up 966 + (212 − 32) = 1,146 B. T. U.

6. How many B. T. U. are required to raise the temperature of 26 pounds of copper from 57° to 93°? Ans. 89.1 B. T. U.

7. Four pounds of a certain substance at a temperature of 212° are mixed with 1 pound of water at 50°; the specific heat of the substance being .03125, what is the resulting temperature of the mixture? Ans. 68°.

8. How many B. T. U. are required to change 13 pounds of water at 59° into steam at 212°? Ans. 14,547 B. T. U.

9. Twenty pounds of steam at 212° are run into a tank containing 340 pounds of water at 42°. What will be the final temperature of the mixture? Ans. 105.11°.

STEAM.

PROPERTIES OF STEAM.

21. **Steam** is *water vapor;* that is, it is *water* changed into a *gaseous state* by the application of *heat.*

The process of changing water (or other liquid) into vapor by means of heat is called **evaporation** or **vaporization.**

When an open vessel containing water is placed in contact with fire, the air contained in the water is first driven off and escapes from the surface. The water in contact with the part of the vessel nearest the fire first receives the heat and expands. Its specific gravity is reduced; that is, it becomes lighter than the cooler water above it, and it rises to the surface, cooler water taking its place. In this manner the water keeps up a circulation until it reaches a temperature of 212°. At this stage the molecules nearest the fire attain such a velocity of vibration that they rise through the water above them, overcome the pressure of the air, and escape in the form of a gas. When this occurs the water boils.

22. Pressure and Temperature.—It is plain that if the pressure on the surface of the water is increased, it will take more work to force the molecules to the surface; that is, more heat must be given to the water to make it boil, and therefore the boiling point will be raised. We have seen that water exposed to the atmospheric pressure of 14.7 pounds per square inch boils at a temperature of 212°. If the pressure is increased to, say, 32 pounds per square inch, the water will not boil until it reaches a temperature of 254°. On the other hand, if the pressure is lowered to 6 pounds per square inch, the water boils at 170°. Hence, we have the following law:

An increase of pressure on the surface of a liquid raises the boiling point; a decrease of pressure lowers the boiling point.

23. Saturated Steam.—Steam in contact with water is called **saturated steam.** This is the condition of steam in a boiler. Steam at a given pressure is also said to be saturated when its temperature is the same as the temperature at which water boils when subjected to the same pressure; this is true even though the steam is entirely separated from water. According to the law just given, the temperature of saturated steam depends only on the pressure. When the steam in a boiler shows a gauge pressure of 60 pounds, its temperature *must be* 307°. A thermometer placed in a boiler could be used to tell the pressure of the steam. It would be as accurate, though not as convenient, as a steam gauge.

The reader is cautioned against the idea that saturated steam necessarily implies "wet" steam. It may be perfectly free from water particles, but it is saturated if it is in any way in contact with water, so that the pressure and temperature are mutually dependent. In the steam boiler, for example, the space above the water, if viewed through a glass-covered opening, appears to be perfectly transparent, as though filled with air, provided the boiler is not working. This shows that the steam that fills this space is perfectly "dry." When, however, the boiler is steaming rapidly, the violent ition may throw up a certain amount of water in the of a spray, that mingles with the steam, giving it the y appearance shown in the exhaust from an engine. m in this condition is "*wet*" *saturated steam.*

4. In physics the word saturation, whence the term *rated steam* has been derived, has a meaning somewhat erent from that commonly assigned to it. It there means filling of a space with vapor to that point where condensa- n begins. Then, we may say that saturated steam is am subjected to a pressure at which condensation is about begin; that is, the slightest abstraction of heat or the htest increase in pressure will cause part of it to condense, l if the steam be separated from the water, the slightest lition of heat will cause it to become superheated.

5. **Superheated Steam.**—Steam separated from water y be heated like air or any other gas until its temperature igher than the boiling point corresponding to its pressure.

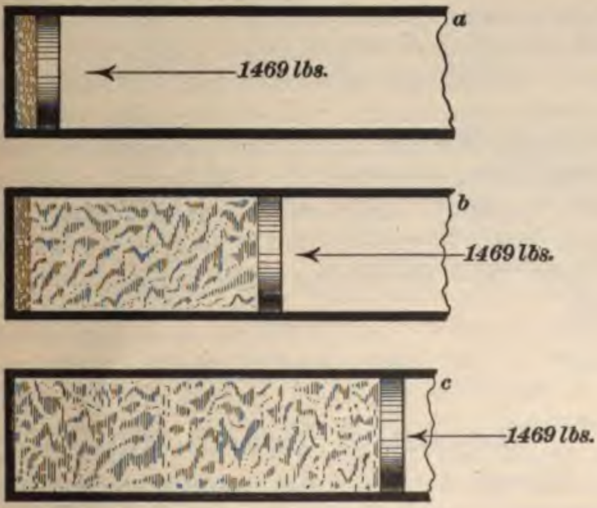

FIG. 2.

illustrate, put a little water in a cylinder open to the nosphere, as shown in Fig. 2 at *a*. Suppose that the area of the cylinder is 100 square inches; then, the pressure of the atmosphere upon the piston is 14.69 × 100 = 1,469 pounds. The number 14.69 is a little more exact than 14.7.

When a part of the water is changed to steam, as at *b*, Fig. 2, the steam is in a saturated state, and at this pressure its temperature cannot be higher than 212°. When, however, the water is all changed to steam, as at *c*, Fig. 2, any farther addition of heat raises its temperature, while the pressure remains at 14.69 pounds per square inch. Steam in this latter condition is known as superheated steam.

The specific heat of superheated steam at constant pressure is .4805, or, say, .48 for ordinary purposes; that is, .48 of 1 B. T. U. will raise the temperature of 1 pound of superheated steam 1 degree. The temperature of saturated steam cannot be raised if the pressure remains constant. All the heat is expended in changing water to steam, and until all the water is vaporized the temperature remains constant.

26. If the steam in the cylinder has been subjected to a uniform pressure greater than that of the atmosphere, its temperature will be correspondingly higher; but as long as any water remains, any addition of heat will merely change more of the water to steam without increasing the temperature. As soon, however, as the last drop of water is gone, the effect of adding more heat will be to increase the temperature. We may, therefore, define **superheated steam** as steam separated from water and heated so as to give it a temperature higher than the boiling point corresponding to its pressure.

STEAM TABLES.

PROPERTIES OF SATURATED STEAM.

27. Whenever the pressure of saturated steam is changed, there are other properties that change with it. These properties are the following:

1. The temperature of the steam, or, what is the same thing, the boiling point.

2. The number of B. T. U. required to raise 1 pound of water from 32° (freezing) to the boiling point corresponding to the given pressure. This is called the **heat of the liquid.**

3. The number of B. T. U. required to change the water at the boiling temperature into steam at the same temperature. This is called the **latent heat of vaporization,** or simply **latent heat.**

4. The number of heat units required to change 1 pound of water at 32° to steam of the required temperature and pressure. This is called the **total heat of vaporization,** or simply **total heat.**

It is plain that the total heat is the sum of the heat of the liquid and the latent heat. That is, total heat = heat of liquid + latent heat.

5. The **specific volume** of the steam at the given pressure; that is, the number of cubic feet occupied by 1 pound of steam of the given pressure.

6. The **density** of the steam; that is, the weight of 1 cubic foot of the steam at the given pressure.

28. All the above properties vary with the pressure of the steam. For example, if steam is at atmospheric pressure, the temperature is at 212°; the heat of the liquid is 180.531 B. T. U.; the latent heat, 966.069 B. T. U.; the total heat, 1,146.6 B. T. U. A pound of steam at this pressure occupies 26.37 cubic feet and 1 cubic foot of the steam weighs about .037928 pound. When the pressure is 70 pounds per square inch above vacuum, the temperature is 302.774°; the heat of the liquid is 272.657 B. T. U.; the latent heat is 901.629 B. T. U.; the total heat, 1,174.286 B. T. U. A pound of the steam occupies 6.076 cubic feet, and 1 cubic foot of the steam weighs .164584 pound.

These properties have been determined by direct experiment for all ordinary steam pressures. They are given in the Table of the Properties of Saturated Steam.

29. Explanation of Table.—Column 1 gives the pressures from 1 to 300 pounds. These pressures are above vacuum. The steam gauges fitted on steam boilers register the pressure above the atmosphere. That is, if the steam is at atmospheric pressure, 14.7 pounds per square inch, the gauge registers 0. Consequently, the atmospheric pressure must be added to the reading of the gauge to obtain the pressure above vacuum. In using the table, care must be taken *not* to use the gauge pressures without first adding 14.7 pounds per square inch for places at sea level. As the pressure of the atmosphere varies with the altitude, the true atmospheric pressure can always be obtained by consulting the barometer. The barometric reading should be reduced to pounds pressure per square inch and added to the gauge pressure in order to obtain the correct absolute pressure for the time and place. However, in nearly all engineering calculations, it is customary to take the pressure of the atmosphere as 14.7 pounds per square inch, which value will hereafter be used unless stated otherwise.

Pressures registered above vacuum are called **absolute pressures.** The pressures given in column 1 are *absolute.*

Column 2 gives the temperature of the steam when at the pressure shown in column 1.

Column 3 gives the **heat of the liquid.** It will be noticed that the values in column 3 may be obtained, approximately, by subtracting 32° from the temperature in column 2. If the specific heat of water were exactly 1.00, it would, of course, take exactly 212 − 32 = 180 B. T. U. to raise 1 pound of water from 32° to 212°. But experiment shows that the specific heat of water is slightly greater than 1.00 when the temperature of the water is above 62°, and it therefore takes 180.531 B. T. U. to raise 1 pound of water from 32° to 212°.

Column 4 gives the **latent heat of vaporization,** which is seen to decrease slightly as the pressure increases.

Column 5 gives the **total heat of vaporization.** The values in column 5 may be obtained by adding together the corresponding values in columns 3 and 4.

Column 6 gives the weight of 1 cubic foot of steam in pounds. As would be expected, as the pressure increases, the steam becomes denser and weighs more per cubic foot.

Column 7 gives the number of cubic feet occupied by 1 pound of steam at the given pressure. It will be noticed that the corresponding values of columns 6 and 7 multiplied together always produce 1. That is, for 31.3 pounds pressure gauge, $.11088 \times 9.018 = 1.000$, nearly.

Column 8 gives the ratio of the volume of 1 pound of steam at the given pressure and the volume of 1 pound of water at 39.1°. The values in column 8 may be obtained by dividing 62.425, the weight of 1 cubic foot of water at 39.1°, by the numbers in column 6.

30. Directions for Using Steam Table.—Manifestly it would be impossible to compile Steam Tables that would include the values corresponding to all pressures. The table here given covers the range of pressures likely to be met in practice. For values that are not given in the table, though within its range, a method of calculation, known as **interpolation,** may be used. In finding the values of t, q, L, etc. for an absolute pressure of, say, 76.35 pounds per square inch, we must make use of the two values of t, q, L, etc., and also of the two values of p given in the table that are nearest to 76.35 pounds; that is, the nearest given value of p that is less than 76.35 pounds and that which is greater than 76.35 pounds. In the present case, these two values are 76 pounds and 78 pounds. In like manner, for any other given value of p that, though within the range of the table, is not given, we must make use of the two values of p between which it is included.

31. The method of using the tables is illustrated by the following examples and their accompanying solutions.

What are the values of t, q, L, H, V, and W for steam whose gauge pressure is 61.65 pounds per square inch?

The pressures in the Steam Table are absolute pressures; hence, when the gauge pressure of steam is given, 14.7 must be added to it in order to use it in connection with the table.

Therefore,

$$p = 61.65 + 14.7 = 76.35 \text{ pounds per square inch.}$$

Turning to the tables, we find that this pressure lies between the two given values 76 and 78.

(*a*) To find t (temperature):

$$\begin{array}{lr} \text{For } p = 78 \text{ pounds, } t = & 310.123^\circ \\ \text{For } p = \underline{76} \text{ pounds, } t = & \underline{308.344^\circ} \\ \text{Difference, } 2 \text{ pounds,} & 1.779^\circ \end{array}$$

For a difference in pressure of 2 pounds, we have a difference in temperature of 1.779°. A difference in pressure of 1 pound would, therefore, give a difference in temperature of $\frac{1.779}{2} = .8895^\circ$. The actual difference in pressure for this case is $76.35^\circ - 76^\circ = .35^\circ$. Hence, the actual difference in temperature would be $.35 \times .8895 = .311325^\circ$, say, .311°. This means that if the pressure of saturated steam is changed from 76 pounds per square inch to 76.35 pounds per square inch, its temperature is raised through .311°. Its temperature at 76 pounds pressure is 308.344°, consequently, its temperature at 76.35 pounds pressure is $308.344 + .311 = 308.655^\circ$. Ans.

(*b*) To find q (sensible heat):

$$\begin{array}{lr} \text{For } p = 78 \text{ pounds, } q = & 280.170 \text{ B. T. U.} \\ \text{For } p = \underline{76} \text{ pounds, } q = & \underline{278.350} \text{ B. T. U.} \\ \text{Difference, } 2 \text{ pounds,} & 1.820 \text{ B. T. U.} \end{array}$$

For a difference in 1 pound pressure there will be a difference in q of $\frac{1.820}{2} = .91$ B. T. U.; for a difference in .35 pound pressure there is a difference in q of $.91 \times .35 = .3185$ B. T. U. Hence, the sensible heat q, corresponding to a pressure of 76.35 pounds per square inch, is $278.350 + .3185 = 278.6685$ B. T. U. Ans.

(*c*) To find L (latent heat):

For $p = 76$ pounds, $L = 897.635$ B. T. U.
For $p = \underline{78}$ pounds, $L = \underline{896.359}$ B. T. U.
Difference, 2 pounds, 1.276 B. T. U.

For a difference of 1 pound pressure, the difference in latent heat is $\frac{1.276}{2} = .638$ B. T. U.

$$.638 \times .35 = .2233 \text{ B. T. U.}$$

By comparing p and L in the table, it will be seen that as p increases L decreases. In the present case, therefore, we must subtract from the value of L corresponding to a pressure of 76 pounds the difference due to the actual difference in pressures.

That is,

For $p = 76.35$ pounds, $L = 897.635 - .2233$
$= 897.4117$ B. T. U. Ans.

(*d*) To find H (total heat):

For $p = 78$ pounds, $H = 1{,}176.529$ B. T. U.
For $p = \underline{76}$ pounds, $H = \underline{1{,}175.985}$ B. T. U.
Difference, 2 pounds, .544 B. T. U.

As above, $\frac{.544}{2} = .272$; $.272 \times .35 = .0952$ B. T. U.

Hence,

For $p = 76.35$ pounds, $H = 1{,}175.985 + .0952$
$= 1{,}176.0802$ B. T. U. Ans.

(*e*) To find W (weight per cubic foot):

For $p = 78$ pounds (pressure), $W = .182229$ pound (weight).
For $p = \underline{76}$ pounds (pressure), $W = \underline{.177825}$ pound (weight).
Difference, 2 pounds (pressure), .004404 pound (weight).

Proceeding as before,

$$\frac{.004404}{2} = .002202; \quad .002202 \times .35 = .0007707.$$

Hence,

For $p = 76.25$ pounds, $W = .177[illegible] + .00[illegible]$
$= .178[illegible]$ pound. Ans.

(*f*) To find *V* (volume of 1 pound)—

For $p = 76$ pounds, $V = 5.624$ cubic feet.
For $p = \underline{78}$ pounds, $V = \underline{5.488}$ cubic feet.
Difference, 2 pounds, .136 cubic foot.

As before,

$$\frac{.136}{2} = .068;\ .068 \times .25 = .0828 \text{ cubic foot.}$$

Here *V* decreases as *p* increases. Hence, as in (*c*), the difference must be subtracted from the value of *V* corresponding to 76 pounds, and we have

For $p = 76.25$ pounds, $V = 5.624 - .0828$
$= 5.6062$ cubic feet. Ans.

EXAMPLE 1.—Calculate the heat required to change 5 pounds of water at 32° into steam at 92 pounds pressure above vacuum.

[illegible] 7 the total heat of 1 pound at 92 pounds [illegible]

[illegible] = [illegible]900.225 B. T. U. Ans.

[illegible] are required to raise 8½ pounds [illegible]

[illegible] the heat of the liquid of 1 pound [illegible] 219.261 − .293 = 218.968 B. T. U. = heat [illegible] pounds it is 218.968 × 8½ = 1,861.228 B. T. U. [illegible]

EXAMPLE [illegible].—How many foot-pounds of work will it require to change 60 pounds of boiling water at 80 pounds pressure, absolute, into steam of the same pressure?

SOLUTION.—Looking under column 4, the latent heat of vaporization is 895.108; that is, it takes 895.108 B. T. U. to change 1 pound of water at 80 pounds pressure into steam of the same pressure. Therefore, it takes 895.108 × 60 = 53,706.48 B. T. U. to perform the same operation upon 60 pounds of water.

53,706.48 × 778 = 41,783,641.44 ft.-lb. Ans.

EXAMPLE 4.—Find the volume occupied by 14 pounds of steam at 30 pounds *gauge* pressure.

SOLUTION.— 30 pounds gauge pressure = 30 + 14.7 = 44.7 absolute pressure. The nearest pressure in the table is 44 pounds, and the volume of a pound of steam at that pressure is 9.403 cubic feet. The volume of a pound at 46 pounds pressure is 9.018 cubic feet. 9.403 − 9.018 = .385 cubic foot, the difference in volume for a difference in pressure of 2 pounds. $\frac{.385}{2} = .1925$ cubic foot, the difference in volume for a difference in pressure of 1 pound. .1925 × .7 = .135 cubic foot, the difference in volume for a difference in pressure of .7 pound. Therefore, 9.403 − .135 = 9.268 cubic feet is the volume of 1 pound of steam at 44.7 pounds pressure. The .135 cubic foot is subtracted from 9.403 cubic feet, since the volume is less for a pressure of 44.7 pounds than for 44 pounds.

$$9.268 \times 14 = 129.752 \text{ cu. ft.} \quad \text{Ans.}$$

EXAMPLE 5.—Find the weight of 40 cubic feet of steam at a temperature of 254° F.

SOLUTION.—The weight of 1 cubic foot of steam at 254.002°, from the table, is .078839 pound. Neglecting the .002°, the weight of 40 cubic feet is, therefore,

$$.078839 \times 40 = 3.15356 \text{ lb.} \quad \text{Ans.}$$

EXAMPLE 6.—How many pounds of steam at 64 pounds pressure, absolute, are required to raise the temperature of 300 pounds of water from 40° to 130° F., the water and steam being mixed together?

SOLUTION.—The number of heat units required to raise 1 pound from 40° to 130° is 130 − 40 = 90 B. T. U. (Actually a little more than 90 would be required, but the above is near enough for all practical purposes.) Then, to raise 300 pounds from 40° to 130° requires 90 × 300 = 27,000 B. T. U. This quantity of heat must necessarily come from the steam. Now, 1 pound of steam at 64 pounds pressure gives up, in condensing, its latent heat of vaporization, or 905.9 B. T. U. But in addition to its latent heat, each pound of steam on condensing must give up an additional amount of heat in falling to 130°. Since the original temperature of the steam was 296.805° F. (see table), each pound gives up by its fall of temperature 296.805 − 130 = 166.805 B. T. U. Therefore, each pound of the steam gives up a total of

$$905.9 + 166.805 = 1{,}072.705 \text{ B. T. U.}$$

It will, therefore, take $\frac{27{,}000}{1{,}072.705} = 25.17$ lb. of steam to accomplish the desired result. Ans.

EXAMPLES FOR PRACTICE.

1. How many foot-pounds of work are required to change 42 pounds of water at the temperature corresponding to a pressure of 88 pounds, absolute, into steam at a temperature corresponding to a pressure of 105 pounds, absolute? Ans. 29,208,194.15 lb.

2. How many B. T. U. are required to convert 25 pounds of water at 32° into 109.6 cubic feet of steam? Ans. 29,541.1 B. T. U.

3. Find the number of heat units required to change 11 pounds of water at 32° into steam at 100 pounds absolute pressure. Ans. 13,000.526 B. T. U.

4. Find the weight of 712 cubic feet of steam at a pressure of 33 pounds, gauge. Ans. 81.689 lb.

5. How many pounds of steam at 47.3 pounds pressure, gauge, are required to raise 120 pounds of water from 55° to 160° at atmospheric pressure? Ans. 12.091 lb.

6. Find the volume of 19 pounds of steam at a pressure of 62 pounds, gauge. Ans. 105.952 cu. ft.

THE PROPERTIES OF SATURATED STEAM.

Pressure above Vacuum in Pounds per Square Inch.	Temperature, Fahrenheit Degrees.	Quantities of Heat in British Thermal Units.			Weight of a Cubic Foot of Steam in Pounds.	Volume.	
		Required to Raise Temperature of the Water from 32° to $t°$.	Total Latent Heat at Pressure P.	Total Heat above 32°.		Of a Pound of Steam in Cubic Feet.	Ratio of Vol. of Steam to Vol. of Eq. Weight of Dist. Water at Temp. of Maximum Density
1	2	3	4	5	6	7	8
p	t	q	L	H	W	V	R
1	102.018	70.040	1043.015	1113.055	.003027	330.4	20623
2	126.302	94.368	1026.094	1120.462	.005818	171.9	10730
3	141.654	109.764	1015.380	1125.144	.008522	117.3	7325
4	153.122	121.271	1007.370	1128.641	.011172	89.51	5588
5	162.370	130.563	1000.899	1131.462	.013781	72.56	4530
6	170.173	138.401	995.441	1133.842	.016357	61.14	3816
7	176.945	145.213	990.695	1135.908	.018908	52.89	3302
8	182.952	151.255	986.485	1137.740	.021436	46.65	2912
9	188.357	156.699	982.690	1139.389	.023944	41.77	2607
10	193.284	161.660	979.232	1140.892	.026437	37.83	2361
11	197.814	166.225	976.050	1142.275	.028911	34.59	2159
12	202.012	170.457	973.098	1143.555	.031376	31.87	1990
13	205.929	174.402	970.346	1144.748	.033828	29.56	1845
14	209.604	178.112	967.757	1145.869	.036265	27.58	1721
14.69	212.000	180.531	966.069	1146.600	.037928	26.37	1646
15	213.067	181.608	965.318	1146.926	.038688	25.85	1614
16	216.347	184.919	963.007	1147.926	.041109	24.33	1519
17	219.452	188.056	960.818	1148.874	.043519	22.98	1434
18	222.424	191.058	958.721	1149.779	.045920	21.78	1359
19	225.255	193.918	956.725	1150.643	.048312	20.70	1292

1	2	3	4	5	6	7	8
p	*t*	*q*	*L*	*H*	*W*	*V*	*R*
20	227.964	196.655	954.814	1151.469	.050696	19.73	1231.0
22	233.069	201.817	951.209	1153.026	.055446	18.04	1126.0
24	237.803	206.610	947.861	1154.471	.060171	16.62	1038.0
26	242.225	211.089	944.730	1155.819	.064870	15.42	962.3
28	246.376	215.293	941.791	1157.084	.069545	14.38	897.6
30	250.293	219.261	939.019	1158.280	.074201	13.48	841.3
32	254.002	223.021	936.389	1159.410	.078839	12.68	791.8
34	257.523	226.594	933.891	1160.485	.083461	11.98	748.0
36	260.883	230.001	931.508	1161.509	.088067	11.36	708.8
38	264.093	233.261	929.227	1162.488	.092657	10.79	673.7
40	267.168	236.386	927.040	1163.426	.097231	10.28	642.0
42	270.122	239.389	924.940	1164.329	.101794	9.826	613.3
44	272.965	242.275	922.919	1165.194	.106345	9.403	587.0
46	275.704	245.061	920.968	1166.029	.110884	9.018	563.0
48	278.348	247.752	919.084	1166.836	.115411	8.665	540.9
50	280.904	250.355	917.260	1167.615	.119927	8.338	520.5
52	283.381	252.875	915.494	1168.369	.124433	8.037	501.7
54	285.781	255.321	913.781	1169.102	.128928	7.756	484.2
56	288.111	257.695	912.118	1169.813	.133414	7.496	467.9
58	290.374	260.002	910.501	1170.503	.137892	7.252	452.7
60	292.575	262.248	908.928	1171.176	.142362	7.024	438.5
62	294.717	264.433	907.396	1171.829	.146824	6.811	425.2
64	296.805	266.566	905.900	1172.466	.151277	6.610	412.6
66	298.842	268.644	904.443	1173.087	.155721	6.422	400.8
68	300.831	270.674	903.020	1173.694	.160157	6.244	389.8
70	302.774	272.657	901.629	1174.286	.164584	6.076	379.3
72	304.669	274.597	900.269	1174.866	.169003	5.917	369.4
74	306.526	276.493	898.938	1175.431	.173417	5.767	360.0
76	308.344	278.350	897.635	1175.985	.177825	5.624	351.1
78	310.123	280.170	896.359	1176.529	.182229	5.488	342.6
80	311.866	281.952	895.108	1177.060	.186627	5.358	334.5
82	313.576	283.701	893.879	1177.580	.191017	5.235	326.8
84	315.250	285.414	892.677	1178.091	.195401	5.118	319.5
86	316.893	287.096	891.496	1178.592	.199781	5.006	312.5
88	318.510	288.750	890.335	1179.085	.204155	4.898	305.8

1	2	3	4	5	6	7	8
p	t	q	L	H	W	V	R
90	320.094	290.373	889.196	1179.569	.208525	4.796	299.4
92	321.653	291.970	888.075	1180.045	.212892	4.697	293.2
94	323.183	293.539	886.972	1180.511	.217253	4.603	287.3
96	324.688	295.083	885.887	1180.970	.221604	4.513	281.7
98	326.169	296.601	884.821	1181.422	.225950	4.426	276.3
100	327.625	298.093	883.773	1181.866	.230293	4.342	271.1
105	331.169	301.731	881.214	1182.945	.241139	4.147	258.9
110	334.582	305.242	878.744	1183.986	.251947	3.969	247.8
115	337.874	308.621	876.371	1184.992	.262732	3.806	237.6
120	341.058	311.885	874.076	1185.961	.273500	3.656	228.3
125	344.136	315.051	871.848	1186.899	.284243	3.518	219.6
130	347.121	318.121	869.688	1187.809	.294961	3.390	211.6
135	350.015	321.105	867.590	1188.695	.305659	3.272	204.2
140	352.827	324.003	865.552	1189.555	.316338	3.161	197.3
145	355.562	326.823	863.567	1190.390	.326998	3.058	190.9
150	358.223	329.566	861.634	1191.200	.337643	2.962	184.9
160	363.346	334.850	857.912	1192.762	.358886	2.786	173.9
170	368.226	339.892	854.359	1194.251	.380071	2.631	164.3
180	372.886	344.708	850.963	1195.671	.401201	2.493	155.6
190	377.352	349.329	847.703	1197.032	.422280	2.368	147.8
200	381.636	353.766	844.573	1198.339	.443310	2.256	140.8
210	385.759	358.041	841.556	1199.597	.464295	2.154	134.5
220	389.736	362.168	838.642	1200.810	.485237	2.061	128.7
230	393.575	366.152	835.828	1201.980	.506139	1.976	123.3
240	397.285	370.008	833.103	1203.111	.527003	1.898	118.5
250	400.883	373.750	830.459	1204.209	.547831	1.825	114.0
260	404.370	377.377	827.896	1205.273	.568626	1.759	109.8
270	407.755	380.905	825.401	1206.306	.589390	1.697	105.9
280	411.048	384.337	822.973	1207.310	.610124	1.639	102.3
290	414.250	387.677	820.609	1208.286	.630829	1.585	99.0
300	417.371	390.933	818.305	1209.238	.651506	1.535	95.8

TYPES OF STEAM BOILERS.

FIRE-TUBE BOILERS.

1. A **steam boiler** is an apparatus whose duty it is to generate steam for power or heating purposes.

2. A boiler consists of the following essential parts: A **furnace** in which the combustion of the fuel takes place; a **vessel** to contain the water to be evaporated; a **steam space** to contain the generated steam; a **heating surface** to transmit the heat of the furnace to the water; a **chimney** to carry away the products of combustion and to give a draft to the fire; various **attachments,** or **fittings,** to feed the boiler with water, to carry away the generated steam, to indicate the pressure of the steam, etc.

3. Boilers are built in a variety of forms to meet the varying requirements of different classes of work. They may be roughly divided into three classes: **stationary, locomotive,** and **marine boilers.**

4. The **plain cylindrical boiler** is shown in Figs. 1, 2, and 3. It consists essentially of a long cylinder called the **shell.** This shell is made of iron or steel plates riveted together as shown in Fig. 1. The ends of the cylinder are closed by flat or hemispherical plates called the **heads** of the boiler. In Fig. 2 the front head is shown carrying the fittings B, C, C_1, and C_2. In this type of boiler the heads are

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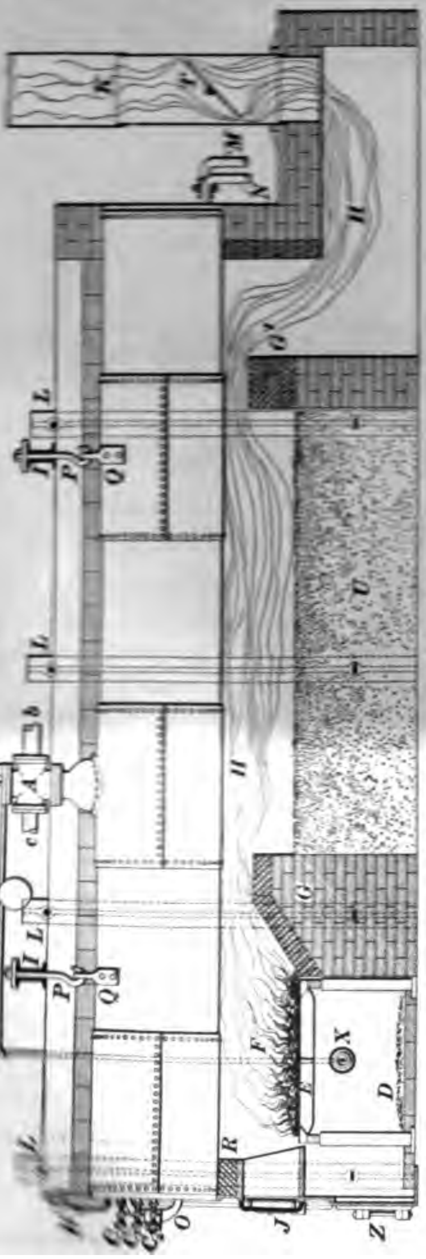

FIG. 1.

often made of thick cast iron, though wrought-iron plate may be used. The hemispherical, or dished, form of head is stronger than the flat head, and is therefore generally used for this type of boiler.

The boiler is enclosed by side walls of brick. The channel beams *I*, *I* are laid across these brick side walls, and the boiler is suspended from these beams by means of the hooks *P*, *P* and eyes *Q*, *Q* (see Figs. 1 and 3), the latter being riveted to the shell. The side walls are supported and kept from buckling by the binders, or buckstaves, *L*, *L* that are bolted together at the top and the bottom. The buckstaves are cast-iron bars of **T** section, as shown in the figure. The eyes *Q*, *Q* are placed about one-fourth the length of the shell from each end. This method of suspending the shell allows it to expand and contract freely when heated or cooled.

The rear end of the shell is enclosed by the rear wall, as is shown in Fig. 1; the wall is continued back, forming the chamber *H*, into which the chimney, or stack, *K* opens. The front of the boiler, shown in Fig. 2, is of cast iron. The front end of the shell touches the firebrick lining *R*, and its weight comes upon the hooks *P*, *P*, the rear wall and firebrick lining *R* simply keeping it in position.

The furnace *F* is placed under the front end of the boiler shell. The fuel is thrown in through the furnace door *J* and burns upon the grate *E*, the ashes falling through the grate into the ash-pit *D*. To insure a supply of air sufficient for the complete combustion of the fuel, the furnace is sometimes supplied with a blower *X*. This consists of a cylinder leading into the ash-pit *D*, into which is led a jet of steam through the pipe *Y*. The jet escapes into the ash-pit with great velocity and carries with it a quantity of air. The air thus carried in is forced through the spaces between the grate bars into the burning fuel, thus producing rapid and complete combustion.

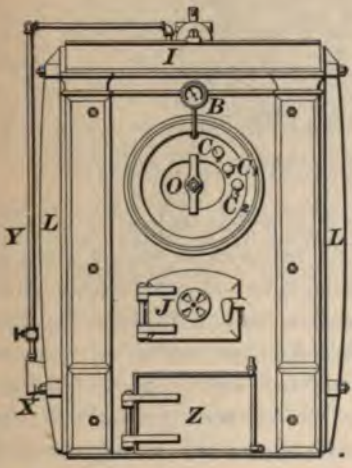

FIG. 2.

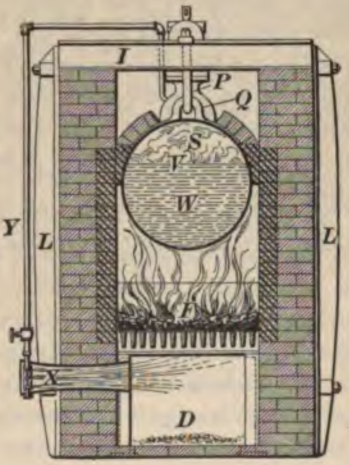

FIG. 3.

5. Behind the furnace is built the brick wall *G*, called the **bridge.** It serves to keep the hot gases in close contact with the under side of the boiler shell. As boilers of this type are generally quite long, a second bridge *G'* is usually added. The gases arising from the combustion of the fuel flow over the bridges *G* and *G'* into the chamber *H* and escape through the chimney *K*. The velocity of flow of the gases, and hence the intensity of the fire, is regulated by the damper *T* that is placed within the chimney. The space *U* between the bridges is filled with ashes or some other good non-conductor of heat. The door *Z* in the boiler front gives access to the ash-pit for the removal of the ashes. The tops of the bridges, the inner surface of the side walls and rear wall, and, in general, all portions of the brickwork exposed to the direct action of the hot gases are made of firebrick (shown in Figs. 1 and 3 by the dark section lining) since this material is able to withstand a very high temperature.

It will be seen by referring to Fig. 3 that the upper portion of the boiler shell is covered with firebrick in such a manner as to prevent the hot gases coming into contact with the shell above the water-line *V*. It is a general rule in the construction and setting of fire-tube boilers that *under no circumstances should the fire-line be carried above the water-line*, for if the hot gases come in contact with the part of the boiler above the level of the water, it will become unduly heated, and thus weakened, and will be liable to rupture. In fact, a great number of boiler explosions are caused by "low water" in the boiler, in which condition the water-line is below the fire-line.

The top of the shell is covered by brickwork or some other non-conducting material to prevent radiation of heat. The boiler is filled with water through the feedpipe *N*, which leads to a pump or injector. When in operation, the water stands at about the level *V*, the space *S* above being occupied by the generated steam. The **safety valve** is shown at *A*. By means of this attachment the steam pressure is kept from rising above the desired point. The pipe *b* is the main steam pipe leading to the engine; the pipe *c* provides for the escape of the waste steam when the safety valve blows off.

The steam gauge *B* indicates the pressure of the steam in the boiler. The gauge is attached to a pipe that passes through the front head into the steam space.

The gauge-cocks C, C_1, and C_2 are placed in the front head of the shell; they are used to determine the water level. For instance, if the cock C_1 is opened and water escapes, it is evident that the water-line is above the cock C_1, while if steam escapes, the level must be below C_1.

The manhole *O* is simply a hole placed in the front head through which a man may enter and inspect or clean the boiler. The hole is closed by a plate and yoke.

To permit the boiler to be emptied, it is provided with a blow-off pipe *M*, through which the water or sediment may be discharged.

These boilers are made from 30 to 42 inches in diameter and from 20 to 40 feet long, though in rare instances they have been constructed with a diameter of 48 or more inches and a length of 60 or even 100 feet.

6. Plain cylindrical boilers are much used in mining districts, where fuel is very cheap; on account of their small water-heating surface, they are very uneconomical and hence are not generally used where fuel is expensive. The advantages of this boiler are: Cheapness of construction, strength, durability, and ease of access for cleaning and repairs.

7. The **flue boiler** differs from the plain cylindrical boiler in having one or more large flues running lengthwise through the boiler shell below the water-line.

Such a boiler is shown in elevation and section in Figs. 4, 5, and 6.

The flues *A*, *A* are fixed at the ends in the front and rear heads of the shell, respectively. The front end of the shell is prolonged, forming the **smokebox** *B*, into which opens the smokestack *C*. The front of the smokebox is provided with a door *E*. The boiler shell is also provided with the

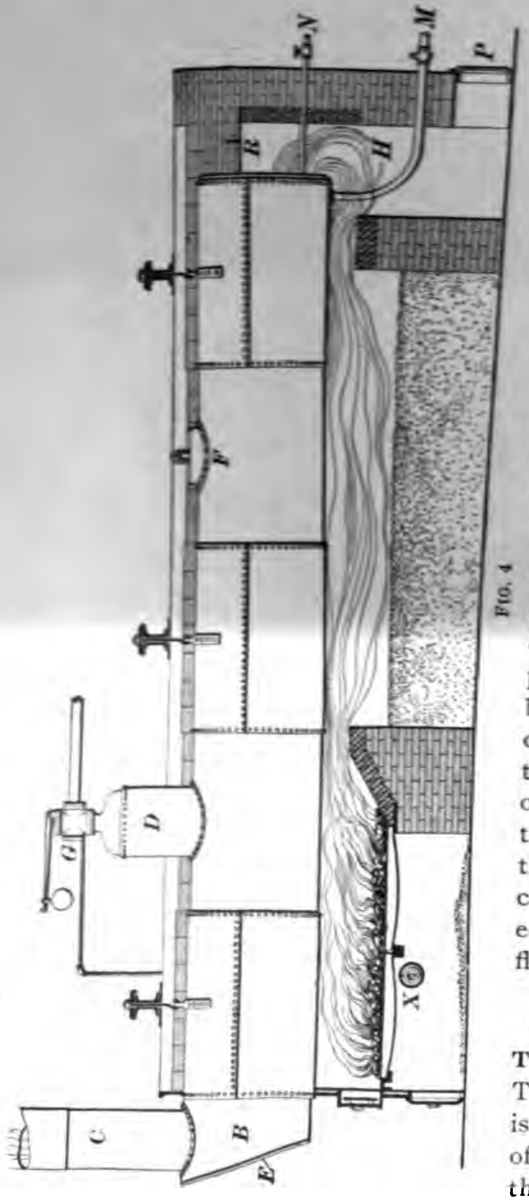

FIG. 4

dome *D*, which forms a chamber where steam may collect and free itself from its entrained water before passing to the engine. The hot gases pass over the bridges to the chamber *H* and then back to the front end through the flues *A*, *A* into the smokebox *B*, and out through the stack *C*. It is plain that the water-heating surface is increased over that of the plain cylindrical boiler by the cylindrical surface of the flues *A*, *A*. In other particulars the description of the plain cylindrical boiler applies equally well to the flue boiler.

8. The Return-Tubular Boiler. This type of boiler is a development of the flue boiler, the two large flues of the latter being replaced by a large number of small tubes. The object of introducing the numerous tubes is to increase the heating surface of the boiler.

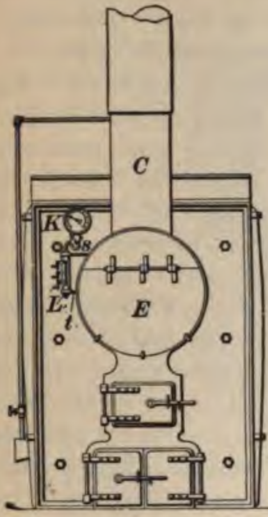

FIG. 5.

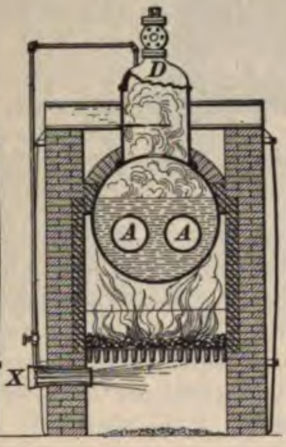

FIG. 6.

A side view of a tubular boiler is shown in Fig. 7; a cross-section through the tubes is shown in Fig. 8. The tubes extend the whole length of the shell; the ends are beaded into holes in the heads of the boiler. The front end

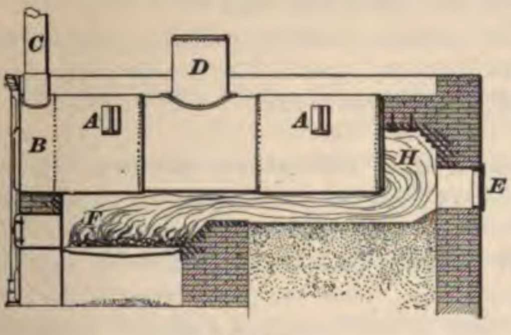

FIG. 7.

of the shell projects beyond the head, forming the smokebox *B*, into which opens the stack *C*.

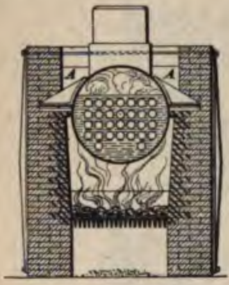

FIG. 8.

The shell is suspended on the side walls by the brackets *A*, *A*, which are riveted to the shell. The boiler is usually provided with a dome *D*, though this is sometimes left off. The walls are built and supported by buckstaves in practically the same manner as those previously described. Since this type of boiler is generally short, one bridge only is used. Firebrick is used for all parts of the wall exposed to the fire or heated gases. The fittings are not shown in the figure. The safety valve would be placed on top of the dome, and the pressure gauge and gauge-cocks would be placed on the front. The manhole is either in one of the heads or on top of the shell. The feedpipe may enter the front head or the top, while the blow-off pipe is placed at the bottom of the shell, at the rear end. Access is given to the rear end of the boiler through the door *E*.

As usual, the furnace *F* is placed under the front end of the boiler. The gases pass over the bridge, under the boiler into the chamber *H*, then back through the tubes to the smokebox *B*, and out of the stack *C*.

The return-tubular boiler is probably used in the United States more than any other. The details of its construction and setting will be shown later.

9. Cornish and Lancashire Boilers.—In the three forms of boilers considered so far, the furnace is placed outside the shell of the boiler; such boilers are said to be **externally fired.** On the invention of the single-flue boiler, the idea was conceived of placing the fire in the flue, and the result is the so-called **Cornish boiler,** a cross-section of which is shown in Fig. 9.

The boiler is set in masonry in such a manner as to form the passages *A*, *A*, and *B*. The grate is supported in the single large flue *C*. The heated gases pass from the furnace to the rear through the flue *C*, they then return beneath the boiler through the flue *B*, and finally return to the rear through the side flues *A*, *A*, and thence out of the chimney. This path of the gases constitutes the **split draft.**

It was formerly the general practice to arrange the brickwork setting so that the gases returned to the front through the side flues *A*, *A* and returned to the rear through the lower flue *B*. It was found, however, that this practice retarded the circulation of the water and rendered the shell more liable to strains due to unequal expansion and contraction. Consequently, the first method of producing the split draft is used almost exclusively in modern practice.

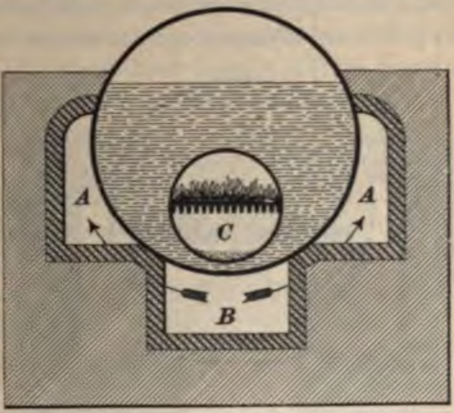

FIG. 9.

As shown in the figure, the brickwork passages are lined with firebrick.

10. The **Lancashire boiler** is a modification of the Cornish type. In order to give a large grate area and a large heating surface for the same diameter of shell, two large furnace flues are substituted for the one flue of the Cornish type. The brickwork setting (Fig. 10) is precisely similar to that of the Cornish boiler, Fig. 9, and the split draft is formed in the same manner.

The large furnace flues of internally fired boilers, of which the Cornish and Lancashire are examples, are subjected to an external collapsing pressure equal to the pressure of the steam. The greater the diameter of the flue, the more liable it is to collapse; consequently, the Lancashire possesses an advantage over the Cornish type in this respect, since each of its two flues is necessarily of smaller diameter than the single flue of the Cornish boiler. Various measures are taken to strengthen the furnace flues of internally fired boilers. They are sometimes made corrugated; again, they are strengthened by having channel irons riveted around them. A very common method, however, is to stiffen them by transverse conical water legs, as shown in Fig. 11. The water legs not only stiffen the flue, but also provide an opportunity for the circulation of the water and split up the gases on their way through the flue, thereby providing an increased heating surface.

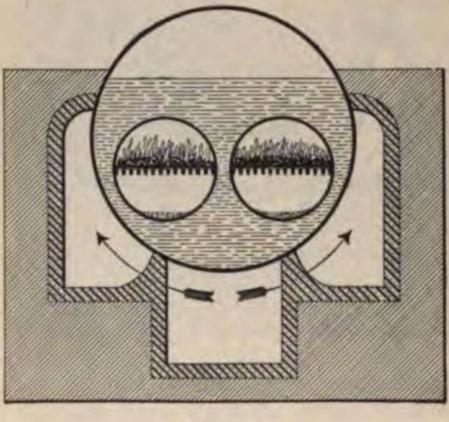
FIG. 10.

11. The **Galloway boiler** is a sort of combination of the Cornish and Lancashire types. It has two internal furnace flues fitted with grates, ash-pit, etc. in the usual manner. Instead of extending through the whole length of the shell, the two flues unite just behind the bridge into one large kidney-shaped flue that extends from this junction to the rear head of the shell. This large flue is strengthened by a large number of water legs of the form shown in Fig. 11. The setting of the Galloway boiler is similar to that shown in Figs. 10 and 11. The draft is split as previously described.

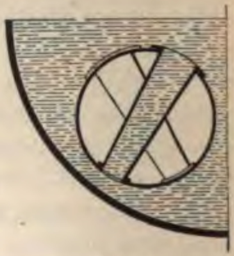
FIG. 11.

12. The Cornish, Lancashire, and Galloway boilers belong to the general class known as **internally fired** boilers. The chief objection to these three types of boilers is the liability of the internal flue to collapse and the straining actions set up by the expansion and contraction of the flue. The chief point in favor of these boilers and in favor of internally fired boilers generally is their economy in the use of fuel. Generally speaking, all conditions being the same, an internally fired boiler is 10 per cent. more economical than an externally fired boiler. This fact is due to the loss of heat by radiation through the brickwork setting of the latter class of boilers.

The three types of boilers just described are extremely popular in England and on the continent of Europe, but they are little used in America.

13. The Clyde Boiler.—A stationary boiler combining the features of the Lancashire and multitubular types is shown in Fig. 12. In consists of a large cylindrical shell *a*, the ends of which are closed by the flat heads *b*, *b*. A large furnace flue *c* of the corrugated type, known technically as the **Morison suspension furnace flue,** extends clear through the boiler and is securely riveted to the two heads, which are flanged inwards for this purpose. Above and beside the furnace flue and parallel thereto and below the water-line is a nest of tubes *d* that extend from head to head. The front ends of these tubes open into a smokebox *e* that connects with the chimney or stack *f*. The flat heads are stayed by through stayrods *g*, *g* in the steam space, which prevent deflection of the heads. The remaining parts of the flat heads are supported by the tubes, which are expanded and beaded over, and by the furnace flue.

The furnace is placed within the furnace flue and, as usual, consists of the grate *h*, the ash-pit *i*, and the bridge *k*. The gases of combustion flow to the rear into the combustion chamber *l* and then pass through the tubes to the front and into the smokebox. The combustion chamber is formed by a thin cylindrical shell attached to the rear end of the

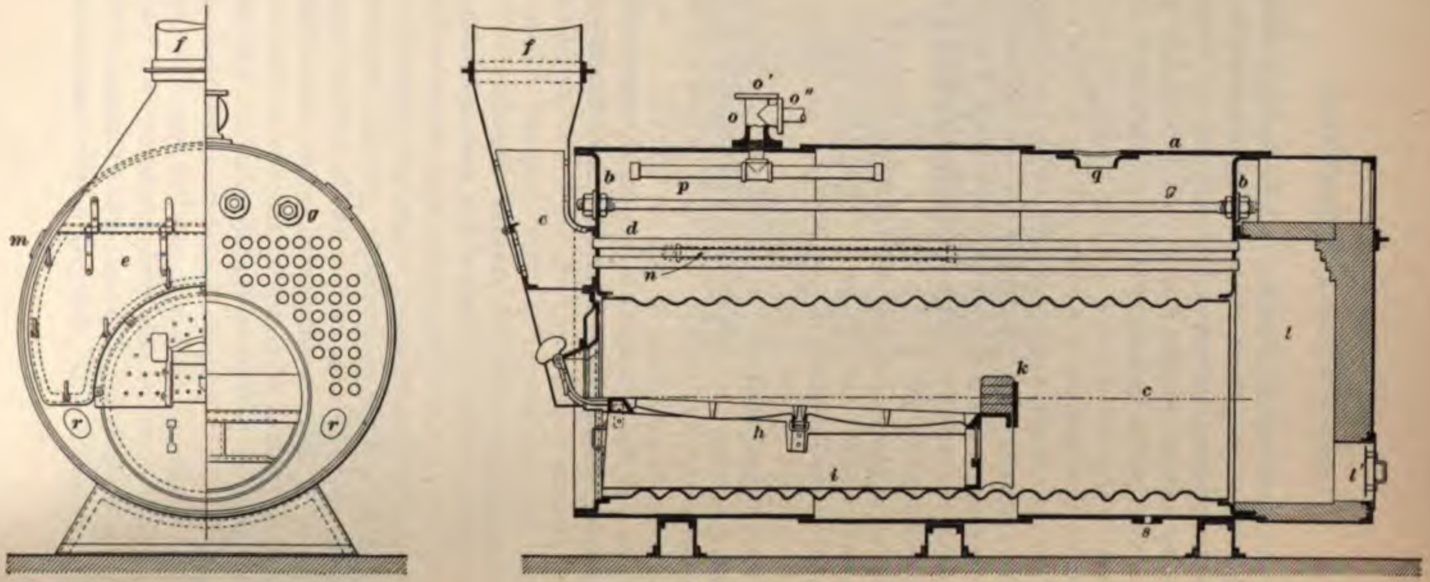

FIG. 12.

boiler, and is lined with firebrick, as shown. A door *l'* gives access to the combustion chamber for the removal of ashes and soot and for the purpose of examination and repair. This type of boiler evidently gives a very large amount of heating surface in proportion to the space it occupies.

The feedwater enters the boiler at *m* and, passing through the internal perforated feedpipe *n*, is discharged downwards alongside the shell in small streams. The various fittings are not shown in the illustration. The steam gauge and water column would naturally be located close to the front end of the boiler; the safety valve is intended to be bolted to the outlet *o'* and the steam pipe to the outlet *o''* of the nozzle *o*. The steam is collected by the dry pipe *p*, which is perforated with numerous slots on top. The dry pipe is fairly effective in freeing the steam from any water that may be mixed with it. The manhole is at *q* and two handholes at *r*. The blow-off is attached at *s*. The boiler is entirely self-contained, i. e., it does not require any brickwork setting. It is simply bolted to three saddles that rest upon and are fastened to a suitable foundation.

A boiler of the kind just illustrated resembles the Scotch boiler used in marine work, and differs from it only in the fact that the combustion chamber is not surrounded by water. For this reason it is often called a **dry-back Scotch boiler**, although some engineers refer to it as the **Clyde boiler**, presumably because this type was originally designed in the shipyards of the Clyde, England.

14. The Locomotive, or Firebox, Boiler.—Next to the multitubular type, the firebox boiler is probably used more than any other type. It is used exclusively in railway service and also largely as a stationary boiler. A large proportion of the small portable combined engines and boilers used for agricultural purposes are of this type. The general construction is shown in Fig. 13. The shell is composed of two differently shaped parts riveted together. The front part of the shell is cylindrical; the rear part is usually of a rectangular cross-section with vertical sides or of a trapezoidal section with inclined sides; in either case the top is semicylindrical. The furnace *F* is a box of the same shape as the rear end of the shell in which it is placed. A space is left between the sides and end of the furnace and the shell; this space is filled with water, as shown at *A*, *A*. A series of tubes extends from the front sheet of the furnace, or firebox, to the front head of the shell. The shell is prolonged beyond the front head, forming a smokebox *B*, into which opens the stack *C*.

As shown in this figure, the "water legs" (as the spaces *A*, *A* are called) extend only as far as the grate, the ash-pit *D* being formed in the brick setting. In many boilers of this type the water legs extend to the bottom of the ash-pit, and sometimes there is a water space below the ash-pit; that is, the furnace and ash-pit are entirely surrounded by water and no brickwork setting is required.

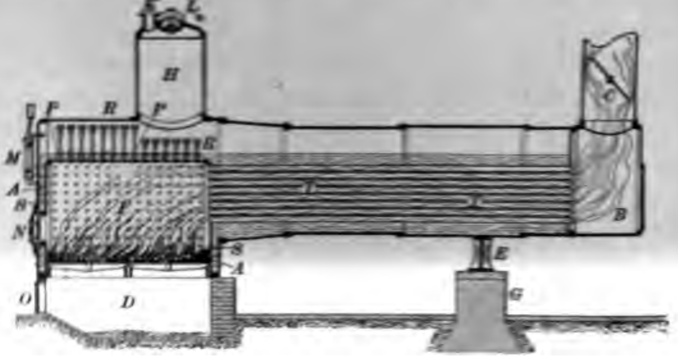

FIG. 13.

The boiler is supported at the front end by the cast-iron cradle *E* that rests upon the masonry foundation *G*. The rear end is supported upon a brick wall, which also forms the ash-pit. The boiler is usually provided with a dome *H*, from which is led the main steam pipe, which is bolted on at *K*. In the figure, the dome is provided with a manhole *L*. The feedwater may be introduced at any convenient point in the shell. The pressure gauge, water glass, and gauge-cocks are attached to the column *M*, which is placed in communication with the interior of the shell. The furnace and ash-pit doors are shown at *N* and *O*, respectively. The safety valve is usually attached to the dome.

Since the flat sides of the furnace and shell are liable to bulge on account of the pressure, they must be braced or stayed. This is accomplished by the staybolts *S*, *S*. The flat top of the firebox is strengthened by a series of parallel girders *P*, *P*. As an additional security, the girders are sometimes attached to the shell by the "sling stays" *R*, *R*.

The gases of combustion pass directly from the furnace through the tubes *T*, *T* to the smokebox *B* and out of the stack *C*. In locomotives, a strong draft is obtained by allowing the exhaust steam to discharge through the smokestack. The escaping steam carries along the air and the escaping gases in the smokebox *B*, thereby drawing a new supply of gases through the tubes *T*, *T* and a supply of air through the grate.

The tubes of the locomotive boiler are about 12 feet long, 2 inches in diameter, and are made of iron or steel. The tubes of stationary and portable boilers of this type are generally of larger diameter, as there is less demand for great quantities of steam.

The locomotive type of boiler evidently is self-contained.

15. The Vertical Boiler.—This type is essentially a modification of the locomotive type placed on end. A common form of vertical boiler is shown in Fig. 14. It consists of a vertical cylindrical shell, in the lower end of which is placed a firebox *F*. The lower rim of the firebox and the lower end of the shell are separated by a wrought-iron ring *k*, to which both are riveted, the rivets going through both plates and ring. The shell and firebox are also stayed together by the staybolts *a*, *a*. The space between the two is filled with water, so that the firebox is surrounded by it. The boiler shell and likewise the grate *E* rest upon a cast-iron base *D* that forms the ash-pit. A series of vertical tubes *t*, *t* extend from the top sheet of the firebox to the upper head of the shell. The tubes serve as stayrods and strengthen the flat surfaces that they connect. The upper ends of the tubes open directly into the chimney or smokestack *K*. The gases from the furnace thus pass directly through the tubes and out of the stack.

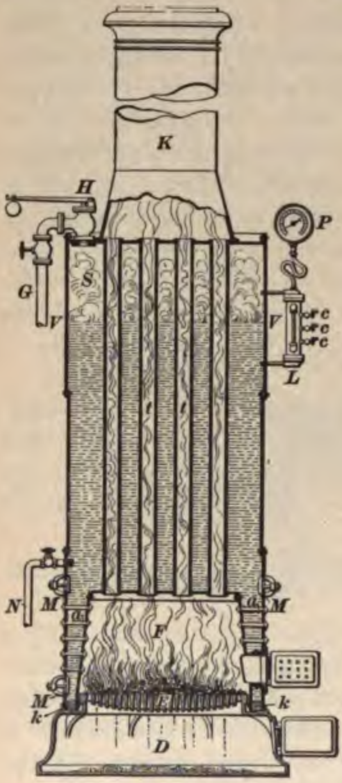

FIG. 14.

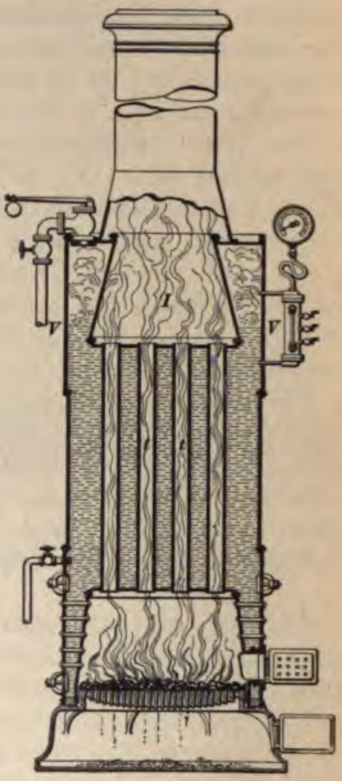

FIG. 15.

The safety valve is shown at *H*, with the main steam pipe *G* leading from it. The pressure gauge *P* and gauge-cocks *c*, *c*, *c* are attached to a column *L* that communicates in the usual manner with the interior of the shell. The construction of this type of boiler does not generally permit the use of manholes, but handholes *M*, *M* are placed in convenient positions for cleaning out mud and sediment.

5. When the tubes extend through the upper head of boiler, as shown in Fig. 14, their upper ends pass through steam space *S* above the water-line *WL*. This is ked upon as a bad feature, since the tubes are liable to come overheated and thus collapse when the boiler is rced.

In the form of vertical boiler shown in Fig. 15, this danger s avoided. A chamber, or smokebox, *l* extends from the upper head of the shell so that its bottom plate is always below the water-line. The upper ends of the tubes *t*, *t* are expanded into the lower plate of this chamber, and therefore the tubes are always surrounded by water from end to end. A vertical boiler constructed in this manner is said to have a **submerged head.** Aside from the submerged head, the construction of the boiler of Fig. 15 is similar to that of Fig. 14.

Vertical boilers are generally wasteful of fuel and are perhaps more liable to explosion than any other type. They are, however, self-contained, require but little floor space, and are easy to construct and repair. For these reasons the vertical type of boiler is very popular with a large class of steam users.

17. The tubular boilers so far described belong to a general class known as **fire-tube boilers,** and any boiler in which the flames and gases of combustion traverse the *inside* of the tube or flue belongs to this class.

WATER-TUBE AND SECTIONAL BOILERS.

18. Of late years, a type of boiler has come into extensive use in which the flames and gases of combustion are in contact with the *outside* of the tubes. The water is contained inside the tubes; hence, these boilers are known as **water-tube boilers.** Some of the leading types of water-tube boilers are described in the following articles.

20. The furnace is of the usual form and is placed under the front end of the nest of tubes. The bridge wall *G* is built up to the bottom row of tubes; another firebrick wall *K* is built between the top row of tubes and the drum. These walls and the baffle plates *S*, *S* force the hot furnace gases to follow a zigzag path back and forth between the tubes. The gases finally pass through the opening *A* in the rear of the wall into the chimney flue.

The feedwater is introduced through the feedpipe *E*. The steam is collected in the dry pipe *F*, which terminates in the nozzles *M* and *N*, to one of which is attached the main steam pipe and to the other the safety valve.

The pressure gauge, cocks, etc. are attached to the column that communicates with the interior of the shell by the small pipes *u* and *v*, the former of which extends into the dry pipe, the latter into the water.

At the bottom of the rear row of headers is placed the mud drum *D*. Since this drum is the lowest point of the water space, most of the sediment naturally collects there. This sediment may be blown out from time to time through the blow-off pipe *P*. The drum *D* is provided with a handhole *Q*. A manhole *R* is placed in the front head of the drum *B*. The heads of the drums are of hemispherical form and therefore do not require bracing. Access may be had to the space within the walls through the doors *I* and *J*.

21. The circulation of water takes place as follows: The cold water is introduced into the rear of the boiler; the furnace being under the higher end of the tubes, the water in that end expands upon being heated, and is also partially changed to steam; hence, a column of mingled water and steam rises through the front headers to the front end of the drum *B*, where the steam escapes from the surface of the water. In the meantime, the cold water fed into the rear of the drum descends to the rear headers through the long tubes *C* to take the place of the water that has risen in front. Thus, there is a continuous circulation in one direction, sweeping the steam to the surface as fast as it is formed and supplying its place with cold water. Most of the sediment sinks to the mud drum *D*, from which it is blown out from time to time.

22. The **Root water-tube boiler** is shown in Figs. 17 and 18, the latter being an end view with the brickwork removed so as to show the various drums and connections. The construction of this boiler is very similar to that of the one just described. There is a nest of inclined tubes, the ends of which are expanded into cast-iron headers. The headers are placed in communication by the U-shaped return bends *a*, *a*. A continuous channel is therefore provided for the circulation of the water through the headers. There is a horizontal overhead drum *A* for each vertical section of tubes. These drums *A*, *A* are placed in communication with the transverse drum *B* by the tubes *C*, *C*. The drum *B* is in turn connected with the lower drum *H* by the two large water legs *D*, *D*. Finally the drum *H* communicates with the rear headers through the tubes *L*, *L*. There is thus an open circuit through the tubes *T*, drum *A*, tubes *C*, drum *B*,

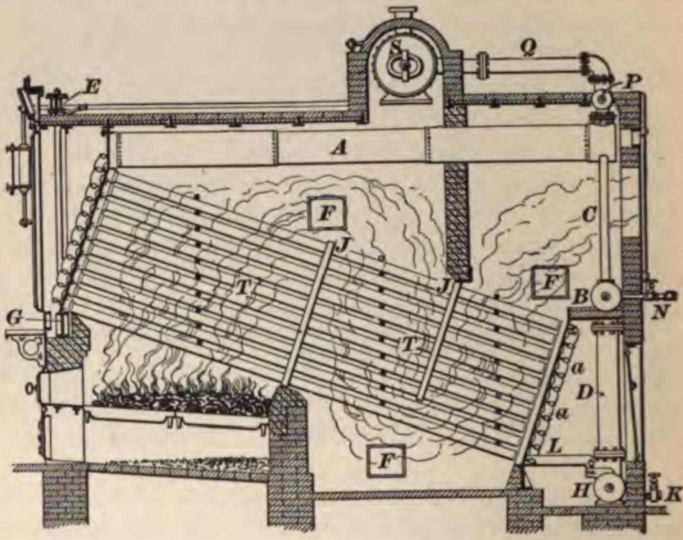

FIG. 17.

water legs *D*, drum *H*, and tubes *L*. The water-line is at about the middle of the drums *A*, *A*, and the steam arising from the surface of the water first passes into the drum *P* and then into the main steam drum *S* through the pipes *Q*, *Q*. The main steam pipe, the safety valve, and other fittings may be attached to the drum *S* at the nozzles *U*, *V*, and *W*.

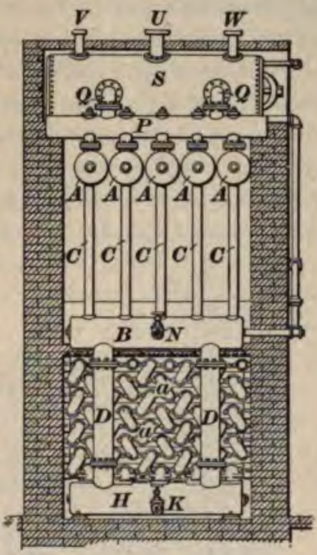

FIG. 18.

The feed-water is introduced into the drum *B* through the feed-pipe *N*. The circulation takes place in the same manner as in the boiler previously described. The drum *H* acts as the mud drum, being at the lowest point of the water circuit. The sediment may be blown out through the pipe *K*.

Access may be had to the interior of the setting through the doors *F*, *F*. The steam drum is provided with a manhole. The rear end of the boiler is supported by the brickwork foundation; the front end is supported by a beam *G* hung from the **I** beam *E*.

The arrangement of the bridge and baffle plates *J*, *J* and the course of the heated gases are precisely the same as in the Babcock and Wilcox boiler.

23. The **Heine water-tube boiler,** shown in Fig. 19, differs in many respects from those already described. It consists of a large main drum *A* that is above and parallel with the nest of tubes *T*, *T*. Both drum and tubes are inclined at an angle with the horizontal that brings the water level to about one-third the height of the drum in front and about two-thirds the height in the rear. The ends of the tubes are expanded into the large wrought-iron water legs *B*, *B*. These legs are flanged and riveted to the shell, which is cut out for about one-fourth its circumference to receive them, the opening being from 60 to 90 per cent. of the cross-sectional area of the tubes. The drum heads are of a hemispherical form and therefore do not need bracing.

The water legs form the natural support of the boiler, the front water leg being placed on a pair of cast-iron columns *E* that form part of the boiler front, while the rear water leg rests on rollers (shown at *F*) that may move freely on a cast-iron plate bedded in the rear wall. These rollers allow the boiler to expand freely when heated.

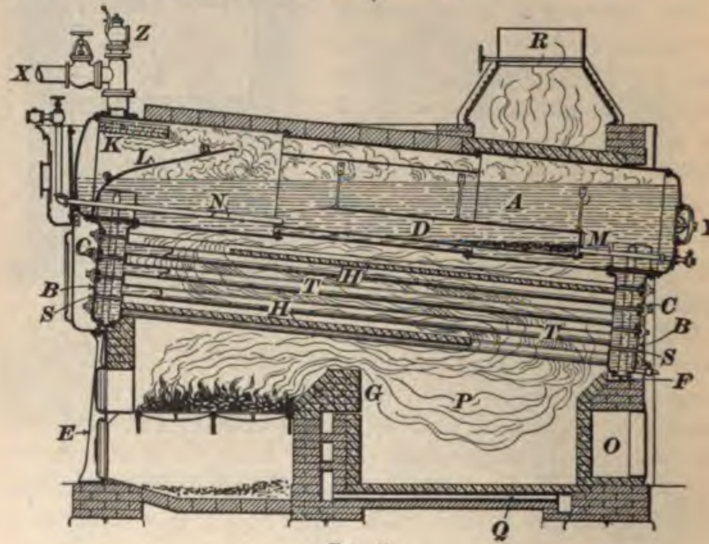

FIG. 19.

The boiler is enclosed by a brickwork setting in the usual manner. The bridge *G*, made largely of firebrick, is hollow, and has openings in the rear to allow air to pass into the chamber *P* and mix with the furnace gases. This air is drawn from the outside through the channel *Q* in the side wall and is, of course, heated in passing through the bridge. In the rear wall is the arched opening *O* that is closed by a door and is further protected by a thin wall of firebrick.

When it is necessary to enter the chamber *P*, the wall may be removed and afterwards replaced.

The feedwater is brought in through the pipe [illegible] which passes through the front head [illegible] the water [illegible] it flows into the mud drum D, which is suspended in the main drum below the water-line and is thus completely submerged in the hottest water in the boiler. This high temperature is useful in precipitating the impurities contained in the feedwater, which settle in the mud drum D and may then be blown out through the blow-off pipe M.

Layers of firebrick *H*, *H* are laid at intervals along the rows of tubes and act as baffle plates forcing the furnace gases to pass back and forth around the tubes. The gases finally escape through the chimney [illegible] placed above the rear end of the boiler. To protect the steam space of the drum from the action of the hot gases, the drum in the vicinity of the chimney is protected by firebrick, as shown in the figure.

The steam is collected and freed from water by the perforated dry pipe *K*. The main steam pipe, with its stop valve, is shown at *X*; the safety valve at *Z*. In order to prevent a combined spray of mixed water and steam spurting from the front header and entering the dry pipe, a deflecting plate *L* is placed in the front end of the drum.

A manhole *Y* is placed in the rear head of the drum. The flat sides of the water legs are stayed together by the stay-bolts *S*, *S*, which are made hollow so as to give access to the outside of the tubes. In front of each tube is placed a handhole *C* that gives access to the interior of the tubes.

Where a battery of several of these boilers is used, an additional steam drum is placed above and at right angles to the drums *A*, *A*.

24. The Stirling boiler, shown in Fig. 20, is a departure from the regular type of water-tube boilers. It consists of a lower drum *A* connected with three upper drums *B*, *B*, *B* by three sets of nearly vertical tubes. These upper drums are connected by the curved tubes *C*, *C*, *C*. The curved forms of the different sets of tubes allow the different parts of the boiler to expand and contract freely without strain.

The boiler is enclosed, as shown, in a brickwork setting that is provided with various holes *H*, *H*, so that the interior may be inspected or repaired. The boiler is suspended from a framework of wrought-iron girders not shown in the figure.

The bridge *E* is lined with firebrick and is built in contact with the lower drum *A* and the front nest of vertical tubes. An arch *D* is built above the furnace, and this, in connection with the bafflers *F*, *F*, directs the course of the heated gases, causing them to pass up and down between the tubes. The arch and bafflers are made of firebrick.

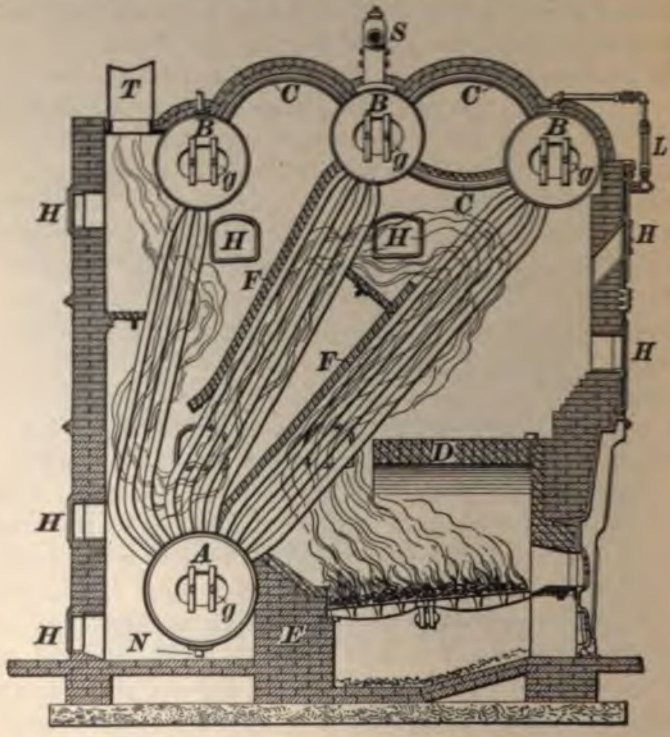

FIG. 20.

The cold feedwater enters the rear upper drum and descends through the rear nest of tubes to the drum *A*, which acts as a mud drum and collects the sediment brought in by the water. A blow-off pipe *N* permits the removal of the sediment. The steam collects in the upper drums *B*, *B*. The steam pipe and safety valve *S* are attached to the middle drum.

The chimney *T* is located behind the rear upper drum. Therefore, the cold feedwater enters the coolest part of the boiler, and the circulation of the water is directly opposite that of the escaping hot gases.

The water column *L*, with its fittings, is placed in communication with the front upper drum. All the drums are provided with large manholes *g*.

25. The **Hazelton** or **porcupine boiler,** shown in Fig. 21, is a vertical water-tube boiler of peculiar form. As shown in the figure, it consists of an upright cylinder *A*, into which are expanded a large number of radial tubes *B*, *B*, whose outer ends are closed, while the inner ends open into the cylinder *A*. The boiler is enclosed in a circular brickwork wall, on top of which is placed the chimney *H*, which is provided with a damper for regulating the draft. Below the tubes the wall is lined with firebrick and projects inwards, forming the furnace *E*. There are several fire doors spaced equidistant around the circumference, one of which is shown at *K*. The grate *G* forms a ring between the central cylinder and the external brick wall. The space below the grate serves as the ash-pit. The water is

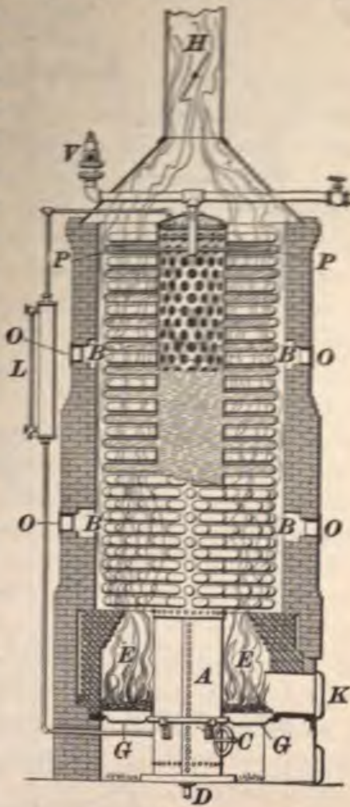

FIG. 21.

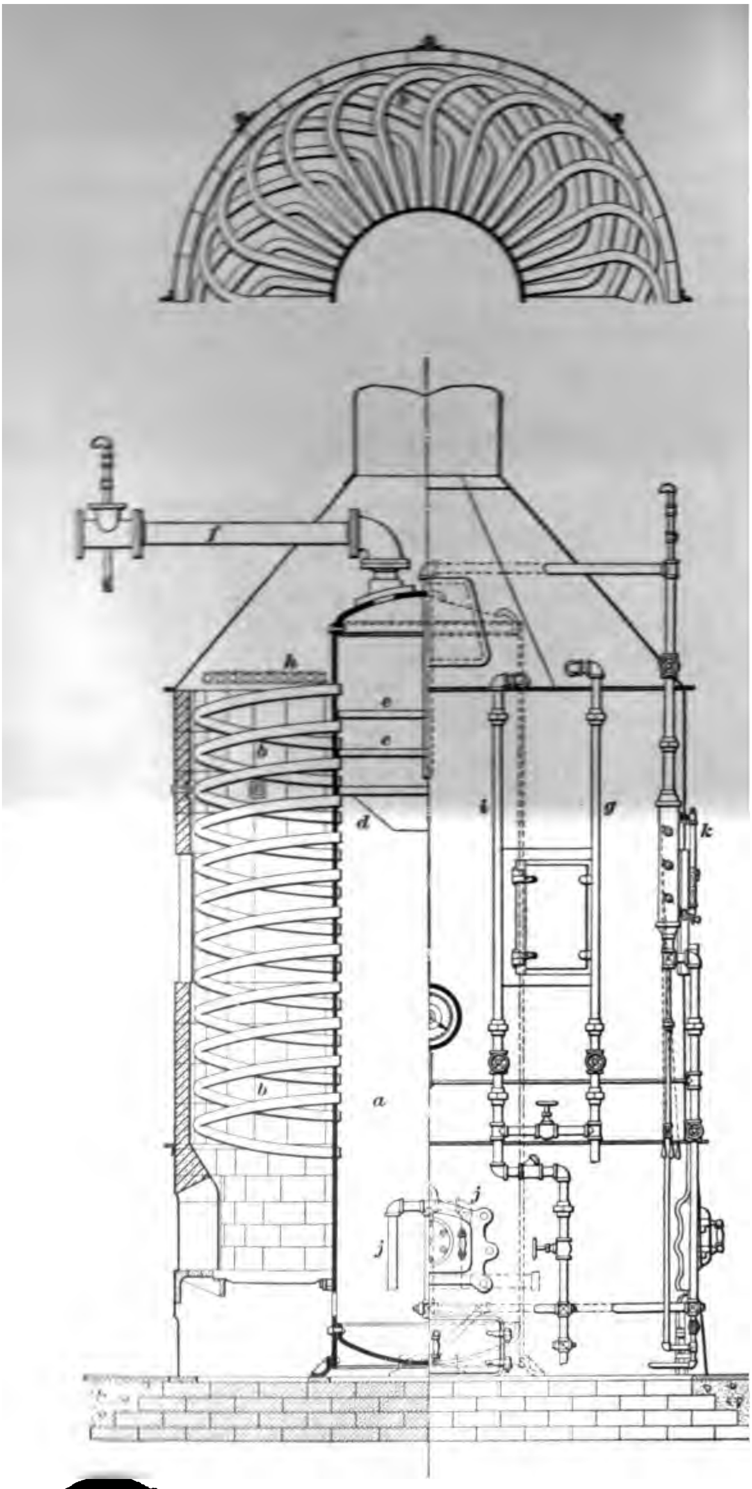

FIG. 22.

contained in the cylinder and tubes. The sediment naturally collects in the bottom of the cylinder and is blown out through the pipe *D* or removed through the manhole *C*. The steam is collected in the perforated dry pipe *P* and led to the main steam pipe *T*. The safety valve is shown at *V* and the water column at *L*. The openings *O*, *O* are left in the wall so that the interior may be inspected.

The heated gases pass from the furnace *E* between the tubes *B*, *B*, and by the time they have reached the chimney, the heat has been mostly absorbed by the water in the tubes.

This boiler does not require to be suspended in any way; the whole weight rests upon the foundation, which may be built in the ground.

26. The **Morrin "Climax"** boiler, shown in Fig. 22, is a water-tube boiler that somewhat resembles the porcupine boiler, and differs from it chiefly in that instead of radial tubes the standpipe or main shell *a* is fitted with a large number of loop-like tubes *b*, *b*, the ends of which are expanded into the shell. The furnace is circular, as in the porcupine boiler, and in order to give free access to the fire, four furnace doors are provided. A deflector plate *d* is fitted to the shell a little above the water level, which tends to throw back any water carried up by the steam. The upper portion of the central shell is divided by a series of diaphragms *e*, *e* into a series of superheating chambers, through which the steam is compelled to circulate successively by the connecting loop-like tubes. The steam thus becomes thoroughly dried and somewhat superheated before it enters the main steam pipe *f*. The feedwater coming from the pump is discharged through the delivery pipe *g* into a spiral feed-coil *h* resting on top of the tubes, where it is heated to a high temperature. It leaves the coil through the pipe *i* and passes downwards, finally being discharged into the bottom of the shell through the internal feedpipes *j*, *j*. The water column *k* is connected to the top and bottom of the central shell. The safety valve is attached to a T placed in the main steam pipe close to the boiler.

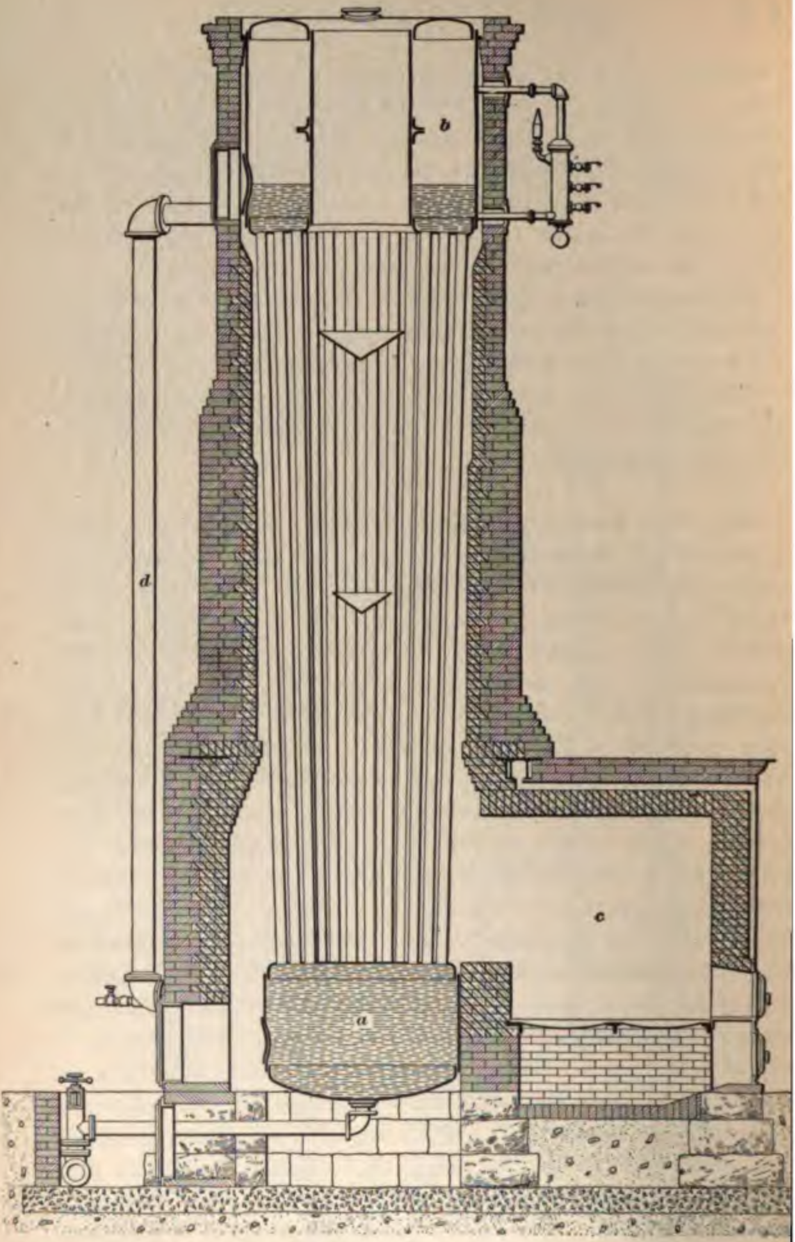

FIG. 23.

27. The **Cahall** boiler may aptly be called a **vertical water-tube boiler.** As a reference to Fig. 23 will show, it consists of a cylindrical mud drum *a* and steam drum *b*, which are connected by nearly vertical tubes. The furnace *c* is placed to one side of the boiler, and the gases of combustion surround the tubes and finally pass through a central passage in the steam drum to the smokestack. The steam becomes slightly superheated in this steam drum, through coming in contact with the surface of the central passage, which is kept at a fairly high temperature by the escaping gases. The steam drum and mud drum are connected by an external circulating pipe *d* that enters the steam drum some distance below the water-line. The feedwater enters the mud drum and, becoming highly heated, rises through the vertical tubes to the steam drum, where the steam bubbles are liberated. Some of the water in the lower part of the steam drum flows continually into the circulating pipe, and since this pipe is not exposed to the heat of the fire, the density of the water in it is much greater than the density of the water in the vertical boiler tubes. In consequence, the water is continually flowing downwards and a rapid circulation is promoted.

28. The **Harrison safety boiler,** shown in Fig. 24, is a sectional safety boiler, but not of the water-tube type. It is composed of hollow cast-iron or steel sections *A*, *A*, called **units,** that are accurately faced and bolted together. Each section is composed of two or more approximately spherical vessels, and the sections are bolted together in a zigzag manner, as shown in the figure, so as to form a solid slab. Each bolt runs from top to bottom through all the units, as shown at *C*. There are several of these vertical slabs of sections suspended side by side from the girders *B*, *B*.

The boiler is enclosed by a brickwork setting that is lined with firebrick. The top of the boiler is likewise covered with firebrick to prevent radiation. The wall is pierced with the openings *D*, *D* for the purpose of inspecting the interior. The bridge *G* and bafflers *H*, *H* direct the gases back and forth between the sections.

fire-tube boiler a split tube can be temporarily repaired very quickly by plugging, and this can be done without throwing the boiler out of service.

Regarding the second objection, it is plain that as water-tube boilers contain but a limited quantity of water, it requires constant feeding to replace the water evaporated into steam. But as pumps and injectors can be regulated to a nicety to supply the required amount of water, the difficulty of maintaining a steady water level is not a serious one.

32. There is an endless variety of water-tube boilers, but the principles of operation are practically the same in all of them. After studying carefully the chapter on water-tube boilers, the student should experience no difficulty in understanding the operation of any water-tube boiler of which he may be placed in charge.

MISCELLANEOUS TYPES.

33. In addition to the types of boilers above described, there are many others embodying special features or of peculiar construction. Some of these are modifications of the types already described; others have nothing in common with them.

34. Of these miscellaneous types, the **Field boiler** may be mentioned. This boiler consists of a vertical cylindrical shell containing a plain flat-top firebox. A single large flue passes from the crown sheet of the firebox through the upper head of the boiler shell to the chimney. The remarkable feature of this boiler is the use of the so-called **Field tubes.** The construction of one of these tubes is shown in Fig. 25. It consists of two concentric tubes, the outer one being closed at one end and open at the other, which is expanded into the crown sheet *C*; the closed end hangs down into the firebox in contact with the hot furnace gases. The inner tube *B* is open at both ends and is suspended inside the outer tube by pins or feathers. The upper end of the inner tube is expanded so as to give a free entrance to the water.

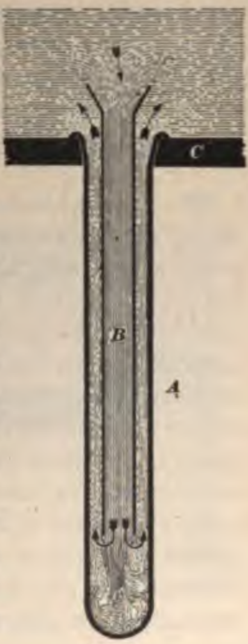

FIG. 25.

The tubes being suspended in the firebox and exposed to intense heat, there is a rapid formation of steam, which rises to the surface through the space between the outer and inner tubes. A stream of water is thus kept continually flowing downwards through the inner tube to supply the place of the rising steam, and the result is a rapid and continual circulation within the tubes.

Field tubes are also used in other boilers. Sometimes they are hung in the furnace flues of Cornish and Lancashire boilers. They are also used in some forms of fire-engine boilers.

CIRCULATION OF WATER IN STEAM BOILERS.

35. Transmission of Heat.—The transfer of the heat generated by burning fuel in the furnace to the water in the boiler is accomplished, in the order named, by *radiation*, *conduction*, and *convection*.

36. Radiation of heat is the transfer of heat through space; **conduction** of heat may be defined as the transfer of heat through solids; and **convection**, as the transfer of heat through liquids or gases. The heat generated in the furnace is transmitted to the plates of the boiler principally by radiation. Convection also plays an important part in the transfer of heat from the fire to the boiler; as the hot gases pass from the fire through the flues and tubes, currents are formed that bring successive portions into contact with the boiler surface, thus enabling them to give up their heat to the boiler. Heat is transmitted through the plates and tubes by conduction and through the water in the boiler by convection.

37. Circulation is the name given to the motion of the water under the influence of heat. The water nearest the plate becomes heated, expands, and thus becoming lighter, rises to the top. In consequence, cold water will flow in from the sides and take its place, become heated in turn, and rise. Now, the rapidity with which the transfer of heat by convection will take place naturally depends on the rapidity of the circulation. If this is interfered with, the transfer of heat will be slow; on the other hand, if the circulation is free, the transfer of heat will be rapid. To a small extent the transfer of heat depends on the quality and thickness of the material through which the heat passes by conduction; the influence of this, however, has experimentally been shown to be small.

38. Water circulation is essential to the efficient operation of a boiler, since with a good circulation more of the heat will be absorbed by the water and less will pass up the chimney. Furthermore, a rapid circulation to a certain extent prevents the deposit of sediment carried in with the feedwater. It also tends to keep all parts of the boiler at a uniform temperature.

39. The circulation of the water in a horizontal return tubular boiler is shown in Fig. 26. The heated water rise from the hottest part of the bottom of the shell, which i directly above the furnace, thus carrying the steam bubble to the surface. The cooler water from the rear of the boile flows in to take the place of that which has risen, and thu circulation is maintained in the general direction indicate by the arrows. It will be noticed that the horizontal direction of the circulation is contrary to that of the gases from the furnace. In cylinder boilers the water is contained in a solid mass, and there is nothing to interfere with the free circulation. In flue boilers and tubular boilers, however, the flues and tubes break up the body of water in such a manner as to cause numerous small currents that oppose the general direction of the circulation more or less. In order to have the circulation interfered with as little as possible, the tubes should not be spaced too closely together.

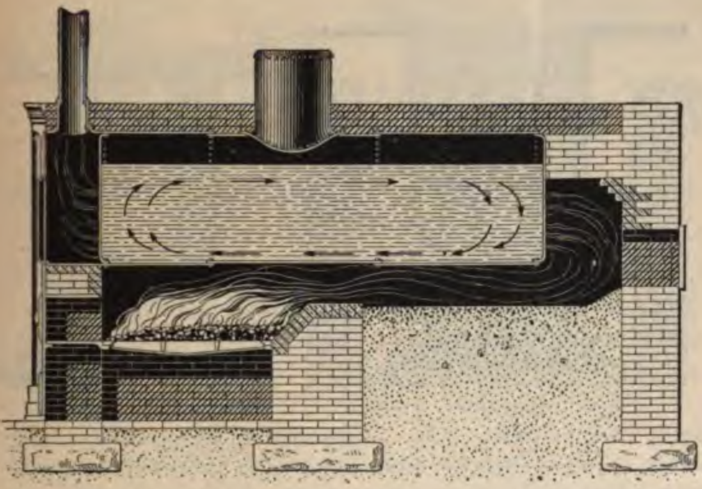

FIG. 26.

40. Uniform Circulation.—It is one of the strong points of correctly designed water-tube boilers that the circulation is strong and uninterrupted by any opposing currents. This is accomplished by passing the water always in the same direction through the series of tubes. The difference between the cylindrical and water-tube boilers in this respect may be illustrated as follows: The cylindrical boiler with its mass of water may be compared to an ordinary kettle in the process of boiling (see Fig. 27). The water rises rapidly around the outer edges and flows downwards in the center. If, however, the fire is quickened, the upward and downward currents interfere with each other and the kettle boils over.

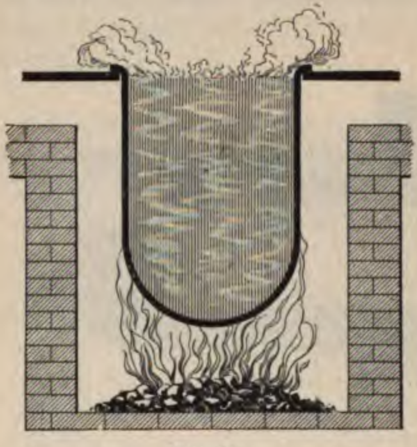

FIG. 27.

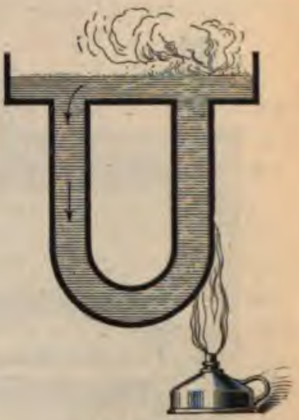

FIG. 28.

The water-tube boiler is and should be identical in principle, with a **U** tube depending from a vessel filled with water with the heat applied to one leg (see Fig. 28). The circulation is set up immediately and proceeds quietly no matter how fierce the fire may be.

BOILER DETAILS.

METHODS OF CONNECTING BOILER PLATES.

1. In the construction of a boiler, the following order of operations is usually followed in the shop: The flat plates from the rolling mill are cut or sheared to the desired size; after being sheared they are placed in a machine that planes the rough edges. Next the rivet holes are punched or drilled in the edge of the plate. The plate is then passed through large rolls and bent to a cylindrical form in such a manner that the corresponding rivet holes in the two edges come opposite one another. One or two bolts are put through to hold the edges together, and the plate is then riveted. The heads are flanged and riveted in place. After the riveting is completed, the tubes are put in and expanded, the stays are put in place, and the boiler is ready for its setting. The details of construction will now be considered.

RIVETING.

2. Rivets.—Common forms of rivets are shown in Figs. 1 to 5. In Figs. 1 and 2 are shown examples of hand riveting; in the first case, the head is hammered down to a cone, while in Fig. 2 the rivet has a cup, or snap, head. This form of head is produced by first hammering the rivet down roughly and then finishing the head by a cup-shaped

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die called the **button set.** The dotted lines in the figure show the shape of the rivet shank before being upset by the hammer.

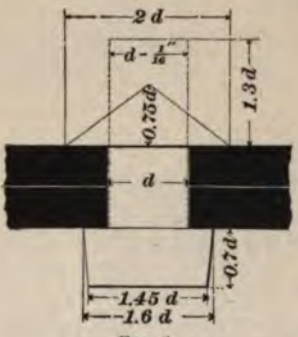

FIG. 1.

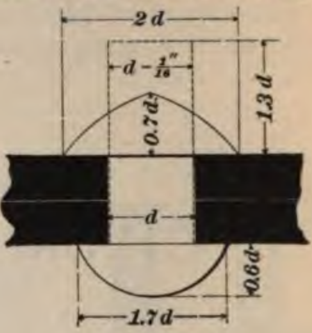

FIG. 2.

3. The rivets shown in Figs. 3 and 4 are examples of machine riveting. The rivet is placed between two dies which are forced together by heavy steam or hydraulic pressure. The most important advantages of machine riveting are the following: By means of the force with which the plates can be held together while the head is being formed, a tighter joint can be made; the heavy pressure used to upset the rivet and form the head causes it to expand and fill the hole more completely than it will when headed by the blows of a hammer; when a large number of rivets is to be driven, machine riveting is cheaper than hand riveting.

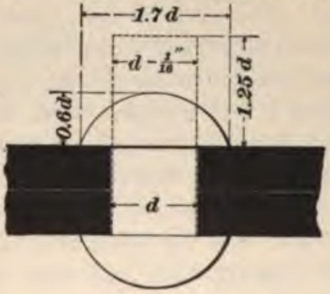

FIG. 3.

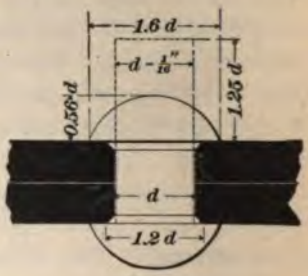

FIG. 4.

A rivet with countersunk head is shown in Fig. 5. Such riveting is sometimes necessary where a smooth surface is needed for the attachment of boiler mountings. In Figs. 4 and 5 the holes in the plates are countersunk slightly under the rivet heads. This provides for an increase in the size of the rivet just under the head and makes the rivet much stronger than is the case where the connection between head and rivet forms a sharp angle, as in Figs. 1, 2, and 3.

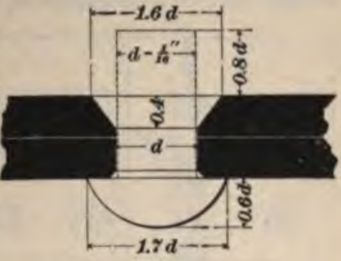

FIG. 5.

As shown in the figures, the rivets, before being headed, are slightly smaller than the hole, so that they may be inserted easily. It is the general rule to make the rivet hole $\frac{1}{16}$ inch larger than the rivet. When the work is properly done, the upsetting action of heading the rivets causes them to fill the holes when headed down.

4. Riveted joints of different forms are shown in Figs. 6 to 9. When one plate overlaps the other and the two are joined with one or more lines of rivets, as shown in Figs. 6 and 7, the joint is said to be **lap-riveted.** When, however, the plates are placed edge to edge, as in Figs. 8 and 9, and the joint is covered with one or two plates, the joint is called a **butt joint.**

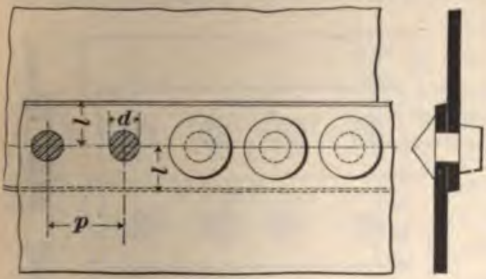

FIG. 6.

5. Fig. 6 represents a **single-riveted lap joint,** that is, the plates are overlapped and joined with one row of rivets. The distance p from center to center of the rivet holes is called the **pitch** of the rivets. The distance l from the center line of the rivet hole is usually made $1\frac{1}{2}$ times the diameter d of the rivet hole.

6. Fig. 7 shows a **double-riveted lap joint.** The rivets may be **staggered,** as shown in the figure, which method is commonly called **zigzag riveting,** or placed one behind the other, as in Fig. 9. In the latter case the joint is **chain-riveted.** In a zigzag riveted joint, the distance from the center of one rivet to the center of the next rivet in the other row is called the **diagonal pitch.** It is quite customary in boiler construction to single-rivet the girth seams and double-rivet the longitudinal seams, since the stress on the latter is twice that on the former, as will be shown further on.

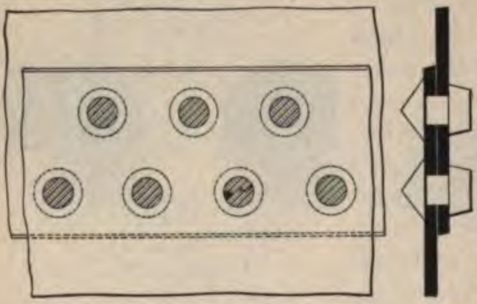
FIG. 7.

7. A **butt joint** with a single cover-plate is shown in Fig. 8, while a butt joint with two cover-plates is shown in Fig. 9. Either may be riveted with one, two, or more rows of rivets; Fig. 9 shows an example of chain-riveting. A well-designed butt joint with two plates will be stronger than one with a single plate. Butt joints are generally used for plates over ½ inch thick and are taking the place of lap joints in good designs of smaller work. When one cover-plate is used on a butt joint, its thickness should not be less than 1⅛ times the thickness of the plate; when two cover-plates are used, the thickness of each should not be less than about ⅝ of the plate thickness.

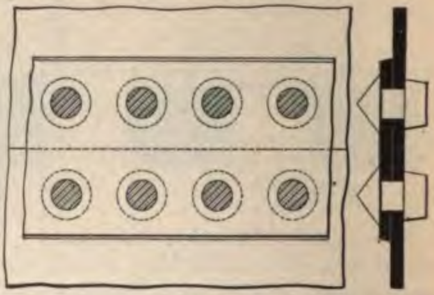
FIG. 8.

8. Arrangement of Joints and Plates.—The plates of externally fired boilers should be arranged so that the riveted joints are as far as possible from the fire. This may be accomplished by using extra large plates for the furnace end of the shell.

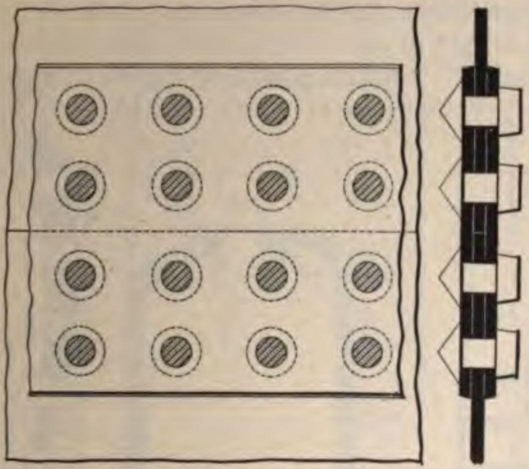

FIG. 9.

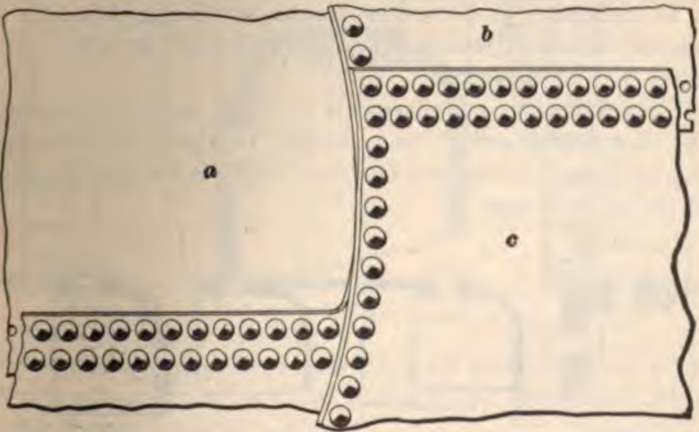

FIG. 10.

Wherever a girth seam occurs, the longitudinal seams should break joint, as shown in Fig. 10. In order to make a tight joint where the three plates come together, the inner plate of the longitudinal joint must be hammered thin at the edge, as shown in Fig. 11.

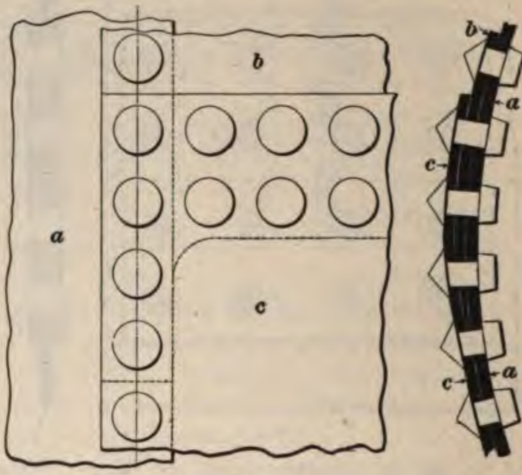

FIG. 11.

In the construction of both vertical and horizontal shells, it is customary to have the inside lap facing *downwards*, since if it faces upwards, a ledge is formed on which sediment may be deposited.

Since wrought-iron plates are stronger in the direction of the fiber, they should be arranged so that the fiber runs circumferentially around the shell; that is, in the direction of the girth seams.

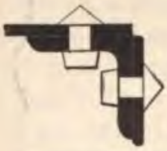

FIG. 12.

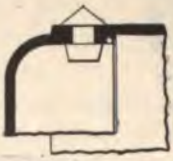

FIG. 13.

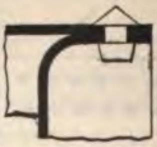

FIG. 14.

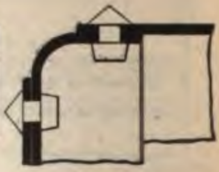

FIG. 15.

9. Connecting Plates.—Different methods of connecting plates at right angles are shown in Figs. 12 to 15. In

Fig. 12 the two plates are riveted to an angle iron. This construction is used sometimes for connecting the heads of a boiler to the shell. As shown in Figs. 13 and 14, the head is flanged and riveted to the shell, while in Fig. 15 the head and shell are connected by a flanged ring. The methods of connection shown in Figs. 13 and 14 are generally considered

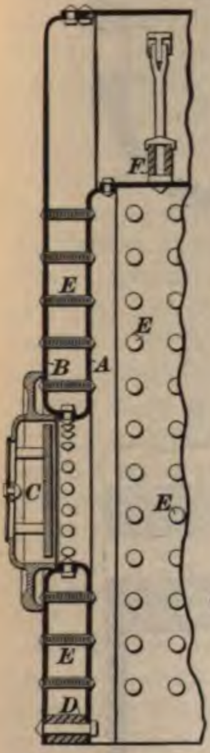

FIG. 16.

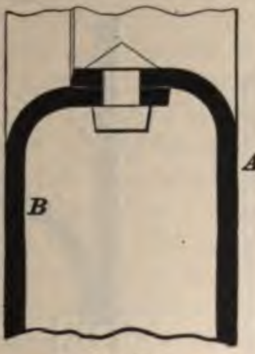

FIG. 17.

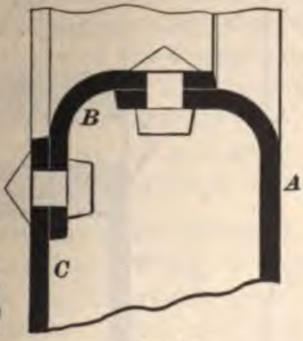

FIG. 19.

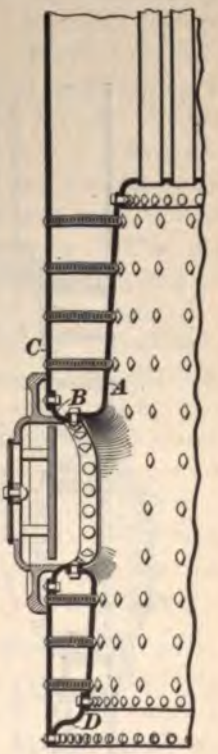

FIG. 18.

preferable to those shown in Figs. 12 and 15, since in the latter methods there are two joints to be kept tight, while in the former there is but one.

Iron or steel for flanging should be of the best quality. The radius of the curve to which the head is flanged should be at least 4 times the thickness of the plate.

Some makers of large boilers prefer to flange the end plates of the shell to receive the head, which is, consequently, a flat disk.

In Figs. 16 to 22 is shown the usual construction of the water legs and furnace doors of vertical and firebox boilers.

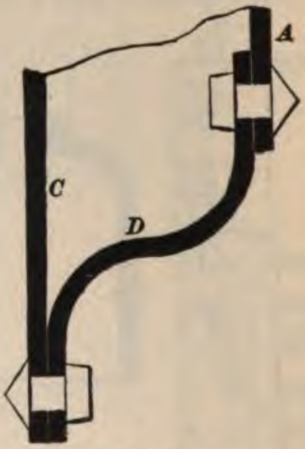

FIG. 20.

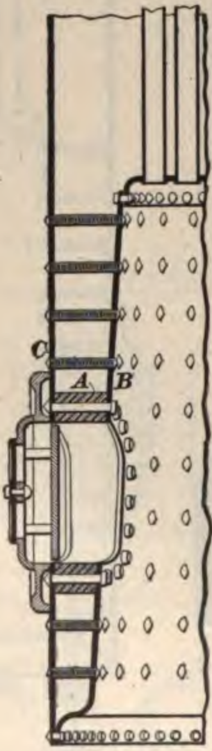

FIG. 21.

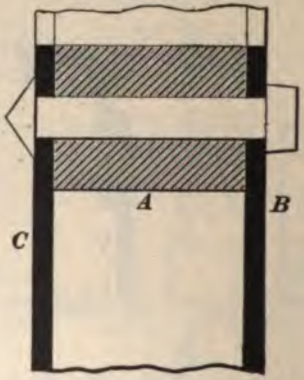

FIG. 22.

Fig. 16 shows the door constructed by flanging the furnace sheet *A* and the front sheet of the boiler *B*. In the figure the joint is single-riveted, although it is frequently double-riveted. An enlarged view of this construction is shown in

Fig. 17. The door *C* is generally made of cast iron and is hinged to a cast-iron frame that is usually held in position by four studs. Sometimes the frame is omitted and the door is made of wrought iron; it is then held in position by riveting the hinges to the boiler.

Around the lower ends of the water legs, or around the bottom of the furnace, and between the inside and outside plates is riveted a wrought-iron ring *D*. In cheap boilers this ring is frequently made of cast iron. Instead of flanging both sheets as in Figs. 16 and 17, the furnace opening is sometimes constructed as shown in Figs. 18 and 19. A hole is cut in the outer sheet *C*, and the furnace sheet *A* is flanged. The flanged ring *B* is then riveted to the plates *A* and *C*, and forms the opening for the door. An enlarged view of this construction is shown in Fig. 19. A flanged ring *D*, Fig. 18, is sometimes used at the bottom of the water leg in place of a wrought-iron ring *D*, Fig. 16, one of the flanges being riveted to the furnace plate and the other to the shell, as shown. An enlarged view of this construction is shown in Fig. 20. In Fig. 21 is shown another method of constructing the opening for the furnace door and the bottom of the water leg. In this construction the wrought-iron ring *A* is placed between the furnace plate *B* and the shell of the boiler *C*, and riveted to them. An enlarged view of this construction is shown in Fig. 22. At the bottom of the water leg the furnace plate is flanged and riveted to the shell, as shown.

10. Rivet holes are either punched or drilled. Punching, while cheaper than drilling, is generally believed to injure the plates, particularly if they are at all hard or brittle. Many makers punch the hole smaller than its intended diameter and then ream it out, thus cutting away the injured metal around the holes. Annealing the plates after punching will partly remove the injury. It is the present practice of good boilermakers to drill all plates, though this practice is not universal.

11. Calking is an upsetting process applied to a riveted joint in order to make it steam-tight. The operation

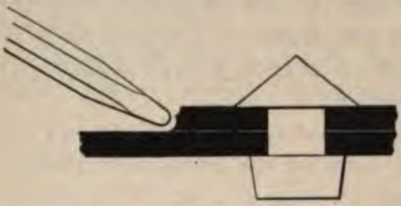

FIG. 23.

shown in Fig. 23. A round-nose calking tool is driven against the beveled edge of the upper plate, forcing the metal in close contact with the lower plate and effectually closing the seam. A tool with a sharp edge should never be used, as it is liable to score the under plate and lead to grooving.

THE BOILER SHELL.

STRESSES ON BOILER SHELLS.

12. If the cylindrical shell shown in Fig. 24 is subjected to an internal pressure, there will be two forces tending to rupture it. One force, indicated by the arrows A, A, acting in the direction of the length, tends to tear the shell in a transverse plane, as $B\ B_1$. The other force, indicated by the arrows C, C, acting perpendicular to the axis, tends to rupture the boiler in a longitudinal plane passing through the axis, as $D\ D_1\ D_2\ D_3$. These two forces are opposed by the tenacity of the material of which the shell is composed. It is easy to see that the magnitude of the force tending to rupture the shell in a transverse plane is equal to the area of the head in square inches times the steam pressure per

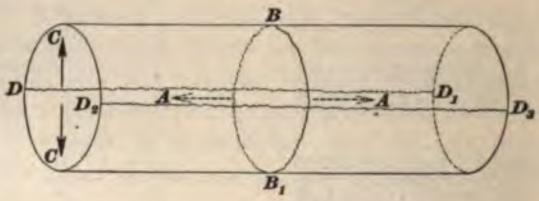

FIG. 24.

square inch. As this force is resisted by the tenacity of the material, the magnitude of the tenacity being measured by the sectional area, the stress per square inch of section of the material is

$$\frac{\text{area of the head} \times \text{pressure}}{\text{area of section}}.$$

13. It can be proved, both by mathematics and by experiment, that the magnitude of the force tending to rupture the shell in Fig. 24, in a longitudinal plane, is equal to the internal diameter multiplied by the length multiplied by the pressure.

To resist this force, we have the combined sectional area of the material of the two sides of the shell. Hence, the stress per square inch of section equals

$$\frac{\text{the internal diameter} \times \text{the length} \times \text{the pressure}}{\text{combined sectional area}}.$$

Suppose we have a plain cylindrical shell constructed of any convenient material. Let the inside diameter be 36 inches, the length 120 inches, the thickness of the shell ¼ inch, and the internal pressure to which it is subjected 100 pounds per square inch.

The pressure on the head and, consequently, the magnitude of the force acting in the direction of the length, is $36^2 \times .7854 \times 100 = 101,787.8$ pounds. This force is resisted by the tenacity of $36.5^2 \times .7854 - 36^2 \times .7854 = 28.471$ square inches of material. Hence, the stress per square inch of section is $101,787.8 \div 28.471 = 3,575.14$ pounds. The magnitude of the force acting perpendicular to the axis equals $36 \times 120 \times 100 = 432,000$ pounds. The area of material resisting this force equals $120 \times .25 \times 2 = 60$ square inches; hence, the unit stress $432,000 \div 60 = 7,200$ pounds per square inch. This shows that there is $7,200 \div 3,575.14$, or about twice as much resistance to transverse rupture as there is to rupture in a longitudinal plane. Hence, it follows that, if the material is proportioned to withstand the force perpendicular to the axis, it will possess ample strength in the other direction.

14. From the foregoing calculation, it is seen that the girth or transverse seams of a boiler need only be single-riveted when the longitudinal seams are double-riveted, or even triple-riveted. When the longitudinal seams are butt joints with two cover-plates and triple-riveted, the girth seams are usually double-riveted.

BURSTING AND SAFE WORKING PRESSURES.

15. Theoretical Bursting Pressure.—For convenience in calculation, the length of the shell is taken as 1 inch. If a boiler is constructed of plates varying in thickness and tensile strength, the least thickness and the lowest tensile strength must be used in calculating the strength of the boiler.

In a cylinder that is on the point of bursting, the resistance of the material to rupture must be equal to the force tending to cause rupture. Hence, a cylinder is on the point of bursting if the product of the diameter and pressure equals the product of twice the thickness of the cylinder and the ultimate tensile strength of the material of which it is composed. It will be noticed that the length of the cylinder has not been taken into account; the length has been assumed to be 1 inch, for the reason previously given. From arithmetic it should be plain that the bursting pressure equals

$$\frac{\text{twice the thickness} \times \text{ultimate tensile strength}}{\text{diameter}}.$$

This may be simplified by using the radius of the cylinder instead of the diameter. Then, as the radius is one-half the diameter, the bursting pressure would be

$$\frac{\text{thickness} \times \text{ultimate tensile strength}}{\text{radius}}.$$

Let t = thickness of cylinder in inches;
R = internal radius in inches;
S = ultimate tensile strength of the material;
P = bursting pressure in pounds;
p = safe working pressure in pounds.

Rule 1.—*To find the bursting pressure of a cylinder, divide the product of the thickness of the cylinder and the ultimate tensile strength of the material by the internal radius.*

Or,
$$P = \frac{tS}{R}.$$

EXAMPLE.—A cast-iron pipe is 10 inches diameter and ½ inch thick. The tensile strength of the iron is 12,000 pounds. At what pressure will the pipe burst?

SOLUTION.—Applying rule **1**, we get

$$P = \frac{\frac{1}{2} \times 12{,}000}{\frac{10}{2}} = 1{,}200 \text{ lb. per sq. in.} \quad \text{Ans.}$$

16. The **efficiency of a joint** may be defined as the ratio of the strength of the joint to that of the solid plate. It is usually expressed in per cent., the strength of the solid plate being considered as the unit (100). Thus, if the efficiency of a joint is 56 per cent., it means that the strength of the joint bears the same proportion to the strength of the solid plate that 56 does to 100.

17. The **average efficiencies of riveted joints** are: for a single-riveted lap joint, 56 per cent.; for a double-riveted lap joint, 70 per cent.; for a triple-riveted lap joint, 75 per cent.; for a double-riveted butt joint with two cover-plates, 76 per cent.; for a triple-riveted butt joint with two cover-plates, 85 per cent.; single-riveted and double-riveted butt joints with one cover-plate give about the same efficiencies as single-riveted and double-riveted lap joints.

18. Rule 1 applies to a cylinder *without* a seam weaker than the material of which the cylinder is constructed. But the longitudinal joints of the shell of a boiler are considerably weaker than the solid plate, and, consequently, a boiler shell will rupture at a pressure depending on the strength of its weakest part. Let f denote the efficiency of the joint, and let the other letters have the same meaning as in the previous rule. Then, the bursting pressure of a boiler shell may be obtained from the following rule:

Rule 2.—*Multiply the thickness of the material by its tensile strength and by the efficiency of the joint, in per cent. Divide the product by 100 times the internal radius.*

Or,
$$P = \frac{t\,S\,f}{100\,R}.$$

In engineers' examinations, the calculation of the bursting pressure is one of the questions usually asked of candidates. Sometimes the efficiency of the joint is given, and sometimes the candidate is merely told what kind of joint is used. In the latter case, use the average efficiency corresponding to the kind of joint, as given in Art. **17.**

EXAMPLE.—A boiler 48 inches in diameter is constructed of steel plate ¼ inch thick, having a tensile strength of 55,000 pounds per square inch. The longitudinal seam being a double-riveted lap joint, what is the bursting pressure?

SOLUTION.—By Art. **18,** the average efficiency of a double-riveted lap joint is 70 per cent. Then, applying rule **2,** we get

$$P = \frac{\frac{1}{4} \times 55{,}000 \times 70}{100 \times \frac{48}{2}} = 401 \text{ lb. per sq. in., nearly. Ans.}$$

19. Safe Working Pressure.—All authorities are agreed that a boiler should not be worked at a pressure near the bursting pressure, but they disagree considerably upon what ratio the safe working pressure should bear to the bursting pressure. This will account for the different results obtained by using different formulas. It is believed that it is the most general practice to make the ratio of the safe working pressure to the bursting pressure 1 : 5. Using this ratio, we have the following rule for safe working pressure:

Rule 3.—*Multiply the thickness of the material by its ultimate tensile strength and by the efficiency of the joint, in per cent. Divide the product by 500 times the internal radius.*

Or,
$$p = \frac{t\,S\,f}{500\,R}.$$

EXAMPLE.—Taking the previous example, what working pressure would you allow?

SOLUTION.—Applying the rule just given, we get

$$p = \frac{\frac{1}{4} \times 55{,}000 \times 70}{500 \times \frac{48}{2}} = 80.2 \text{ lb. per sq. in., nearly. Ans.}$$

20. Board of Supervising Inspectors' Rules.—The Board of Supervising Inspectors of Steam Vessels prescribe the following rules, which, while only in force for marine boilers, are frequently used for stationary boilers:

Rule 4.—*To find the safe working pressure of a cylindrical boiler having single-riveted longitudinal seams, divide the product of the thickness of the shell and the ultimate tensile strength of the material by 6 times the radius.*

Or, $$p = \frac{tS}{6R}.$$

EXAMPLE.—What safe working pressure would be allowed on a boiler with single-riveted longitudinal seams constructed of material ⅜ inch thick and having a tensile strength of 50,000 pounds per square inch. The boiler is 48 inches in diameter.

SOLUTION.—Applying rule 4, we get

$$p = \frac{\frac{3}{8} \times 50{,}000}{6 \times \frac{48}{2}} = 180.2 \text{ lb. per sq. in. Ans.}$$

Rule 5.—*To find the safe working pressure of a cylindrical boiler having double-riveted longitudinal seams, divide the product of the thickness of the shell and the ultimate tensile strength of the material by 5 times the radius.*

Or, $$p = \frac{tS}{5R}.$$

EXAMPLE.—A cylindrical boiler has the following dimensions: Diameter, 36 inches; thickness of shell, .25 inch; ultimate tensile strength of the material, 45,000 pounds per square inch. The seams being double-riveted, find the safe working pressure.

SOLUTION.—Applying rule 5, we have

$$p = \frac{.25 \times 45{,}000}{5 \times 18} = 125 \text{ lb. per sq. in. Ans.}$$

Rules 4 and 5 are based on a ratio of bursting pressure to safe working pressure of about 1 : 3.5; a ratio rather smaller than usually deemed advisable in stationary work.

21. The rules here given are applicable to new boilers. While in use, the plates will gradually waste away or lose in strength by the phenomena called grooving and honeycombing. In that case, the least thickness of plate should be used in calculating the working pressure.

Furthermore, the student is cautioned against assuming that the strength of the shell by itself determines the safe working pressure. A steam boiler is like a chain in that its weakest part determines its strength. The strength of the bracing will also have to be taken into account, and if the bracing is weaker than the shell, the pressure must be reduced to suit the bracing.

STAYING OF FLAT SURFACES.

22. Surfaces That Require Staying.—The surfaces of steam-boiler shells are, in general, either cylindrical, hemispherical, or flat. A cylinder or a sphere subjected to an internal pressure is *self-supporting;* that is, the pressure tends to maintain the cylindrical or spherical form of the vessel and hinders distortion instead of producing it. If the vessel is composed of flat surfaces, however, an internal pressure tends to distort it and give it an approximately spherical form. Then, as flat surfaces are not self-supporting, it follows that they must be stayed or braced.

23. The flat surfaces commonly found in stationary boilers are the boiler heads of the ordinary return-tubular boiler, and the heads, flat sides, and tops of fireboxes of internally fired boilers of the locomotive type.

DIAGONAL STAYS.

24. Crowfoot Braces.—The heads of stationary boilers are supported in various ways. Probably the most common method is to support them by **crowfoot braces,** which are securely riveted to the head and the shell. The crowfoot brace is shown in Fig. 25 (*a*). In this style of brace the crowfoot, or part that is riveted to the head, is formed by welding flat bars to a cylindrical stem. The strap end, or part that is riveted to the shell, is also welded to the stem. An improved form of crowfoot brace is the **McGregor brace,** shown in Fig. 25 (*b*). This brace is formed by a piece of sheet steel, bent in one heat as shown. Being weldless, it may naturally be assumed, and the assumption has been borne out by experiments, that, for equal cross-sectional areas, it will bear a much greater strain than the welded crowfoot brace. It will be observed that the crowfoot of the McGregor brace is formed by splitting the sheet and bending it at a right angle. In the **Huston** improved crowfoot brace, shown in Fig. 25 (*c*), the crowfoot is formed by flanging the plate of which the brace is formed, thus giving probably the strongest form of crowfoot that can be devised.

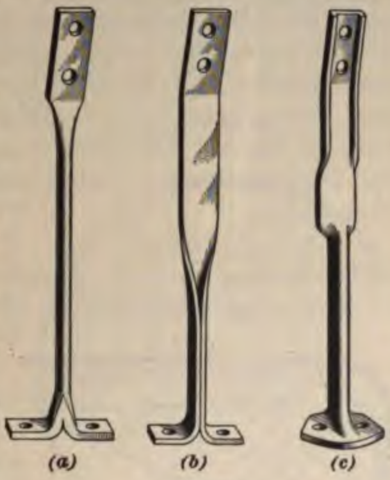
(a) (b) (c)

FIG. 25.

25. Another form of brace used occasionally, and especially for staying the lower part of the head of return-tubular boilers below the nest of tubes, is shown in Fig. 26. The end *A*, instead of being riveted to the head, is threaded and supplied with nuts and taper washers on each side of the head, as shown in Fig. 26. The washers have such a taper that when one of the faces rests against the head, the

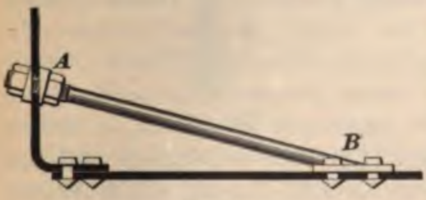

FIG. 26.

other is parallel to the faces of the nuts. The hole through which the stay passes is not threaded, but is made sufficiently large to allow the stay to pass through. In cheaper work, the brace is bent near the head, in order to pass through the head at a right angle, thus doing away with the taper washers. Mechanically considered, this is not such a good arrangement as the one shown in Fig. 26, since the stress on the stay will tend to straighten out the bend and thus allow the head to buckle and give more than with the other design.

26. Gusset stays are occasionally used for staying the heads in large boilers. One of these stays is shown in Fig. 27. A gusset stay consists of an iron or steel plate, as *A*, which is placed between angle irons, as *B*, *B*, which are securely riveted to the head and shell. The plate in turn is riveted to the angle irons. Gusset stays interfere considerably with examination and repair of the boilers, and owing to their absence of flexibility, often induce grooving and cracking of the head-plate. For these reasons they have not found much favor in the United States; however, they are largely used in Europe.

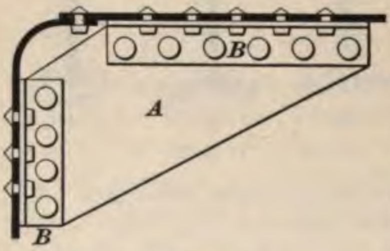

FIG. 27.

27. Bracing With Angle Irons or T Irons.—Small boilers carrying a rather low steam pressure occasionally have the heads braced by angle irons or T irons riveted to the head. For higher steam pressures, the angle irons or T irons may in turn be supported by braces, as shown in Fig. 28, one end of which is riveted to the shell and the other end either forked to straddle the leg of the T iron or flattened to go between two angle irons. Connection between the angle iron or T iron and the brace is then made by a cotter, and, in better work, by a bolt and nut. The stays so far shown are known technically as **diagonal** stays, so called because they are inclined to the surfaces they support.

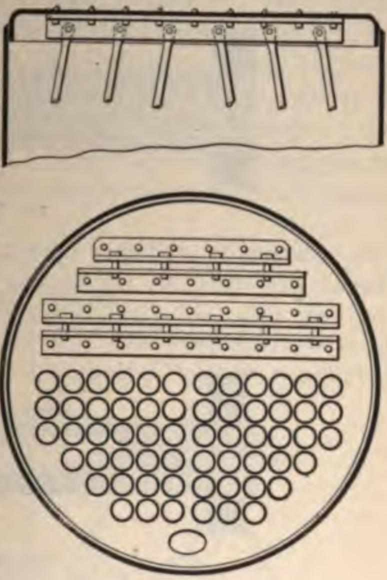

FIG. 28.

DIRECT STAYS.

28. For large boilers carrying high pressures, the most direct way of supporting the heads is to use through stayrods spaced about 14 inches from center to center. These, in the best construction, as shown in Fig. 29, are rods passing through both heads and provided with nuts and washers on both sides of the heads. A large washer on the outside, or a reenforcing leaf, is often riveted to the head, which reduces the bulging under pressure and allows the stayrods to be widely spaced. Channel irons riveted to the inside of the head, and in turn supported by stayrods, have also been used for high-pressure boilers.

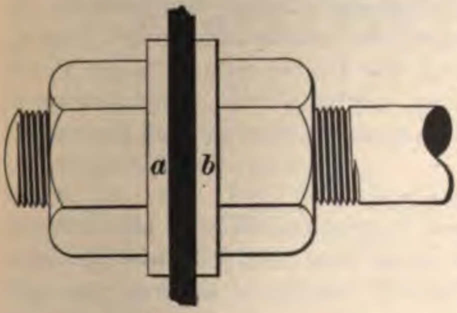

FIG. 29.

29. Staybolts.—For staying the flat surfaces of the water legs of boilers of the locomotive type, the usual and most direct method is to use screw staybolts, one of which is shown in Fig. 30. These screw staybolts are screwed both into the inside and outside sheets and then riveted over at both ends while cold. Staybolts for these surfaces being subjected to a great deal of alternating bending stress (in addition to a direct tensile stress) will sooner or later break off close to the sheets. In order to give warning of this, in good work, holes as *a* in Fig. 31 are drilled axially in the center of each staybolt and extend at least $\frac{1}{2}$ inch beyond the internal surface of the sheets. Should a bolt break, the steam or water issuing from the hole will give warning of the break. In boilers coming under the supervision of the United States Steam Vessel Inspection Service, screw staybolts are not allowed to be used any more unless they are drilled at each end in the manner explained.

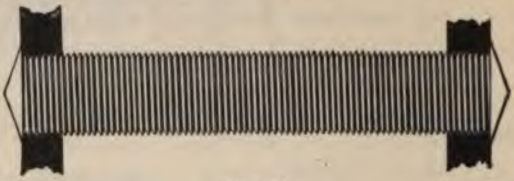

FIG. 30.

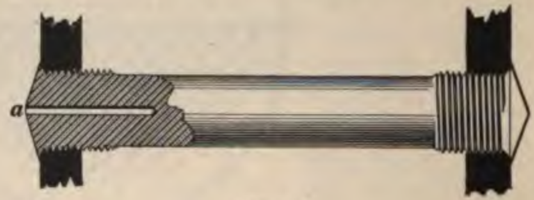

FIG. 31.

30. Hollow Forged Staybolts.—Within the last few years hollow forged staybolts have been placed on the market, in which a hole extends axially all through the bolt. Staybolts of this kind possess more flexibility than solid bolts, and, of course, will give due warning of a break no matter where it may occur.

Instead of riveting over the end of staybolts, they may be fitted with a nut on the outside of the sheet. While this is the common practice in marine boilers of the Scotch type, it is rarely done in stationary boilers.

For high-grade work some boilermakers will turn down the thread on the part of the staybolt between the two sheets, as shown in Fig. 31. This is an excellent practice, as it not only renders the staybolt more flexible, but also tends to reduce corrosion by exposing a much smaller surface to the corrosive action of the water. The stays here shown are at a right angle to the surface they support, and are called **direct stays.**

GIRDER STAYS.

31. The upper plate or **crown sheet** of the furnace of internally fired boilers of the locomotive type is supported in various ways. Probably the most common method is to support it by staybolts screwed and riveted to the sheet and suspended from **girder stays,** as *A* in Fig. 32. These girder stays, one of which is shown in detail in Fig. 33, may in turn be supported by the **sling stays** *E*, *E*, Fig. 32, which are cottered to the angle-iron ring *F*, or may instead be riveted directly to the shell. Some makers of locomotive-type boilers condemn this arrangement as interfering too much with examination and repair;

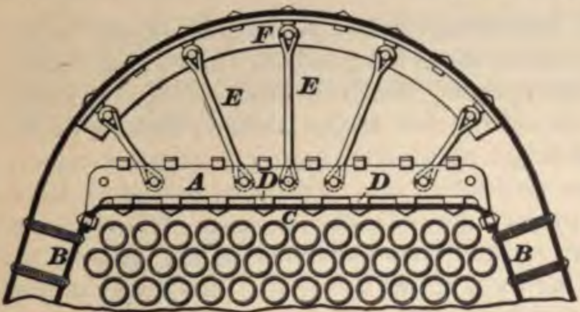

FIG. 32.

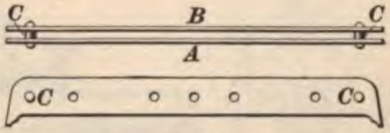

FIG. 33.

they make the girder stays of sufficient strength to support the staybolts. Two methods of suspending the staybolts are shown in Fig. 34, of which the one shown at the left is the most common one. The head is formed with lugs *D*, *D*, which prevent the spreading of the girders. When the crown sheet of a locomotive-type boiler is cylindrical, or approximately cylindrical, it is often supported by long stays screwed and riveted both into the shell and into the crown sheet.

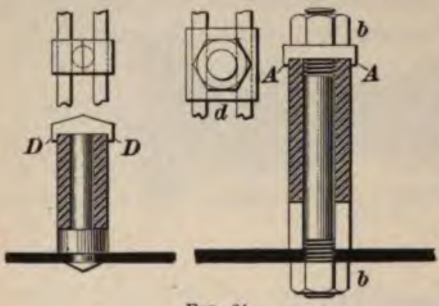

FIG. 34.

32. Fastening Tubes to Heads.—Boiler tubes up to 5 inches in diameter are generally fastened and made steam-tight by expanding them into holes cut into the heads. The tubes are cut off to a length about ½ inch in excess of the outside length between the sheets which are to receive them; they are then driven into place until half of their excess in length projects beyond each tube sheet. The expander is now inserted and the tube expanded tightly into its hole; the projecting ends of the tubes are then nicely beaded over. Tubes and flues above 5 inches in diameter are commonly riveted to the heads, which are flanged to receive the tube.

33. For expanding the tubes, a **Dudgeon roller-tube expander,** shown in Fig. 35, is most commonly used. It

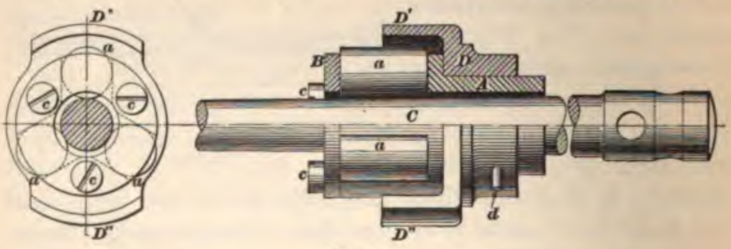

FIG. 35.

consists of a body *A* provided with three slots for the reception of the rollers *a*, *a*, *a*. A plate *B*, fastened to the body by the three screws *c*, *c*, *c*, prevents any longitudinal movement of the rollers. The rollers are forced outwards and rotated by the taper pin *C*, which is provided with a head perforated with two holes at right angles to each other. To make the expander adjustable for different thicknesses of tube sheets, the hood *D* may be moved longitudinally and may be locked in any desired position by means of a small taper pin *d*, which is driven inwards to lock the hood. The operation of the expander is as follows: The expander is pushed into the tube, the projections D', D'' limiting the depth to which the tool may be inserted. A sharp blow with a copper hammer is struck on the head of the pin *C*, forcing it inwards, and, hence, the rollers outwards. Next, a bar is inserted into one of the holes in the head and the pin rotated; the friction between the pin and the rollers causes the rollers, and, consequently, the whole tool, to rotate; this operation expands the tube.

BOILER FITTINGS.

THE SAFETY VALVE.

1. Purpose of Safety Valve.—The safety valve is attached to the boiler to prevent the steam pressure from rising above a certain point. Suppose a boiler is generating steam faster than the engine uses it; it is plain that a large quantity of steam is crowded continually into the steam space of the boiler. The necessary result is a rise in the pressure of the steam. If the pressure continues to rise, it soon becomes greater than the boiler is able to withstand, and an explosion occurs. It is the duty of the safety valve to prevent this increase of pressure.

2. Weighting of Safety Valves.—The safety valve consists simply of a plate, or disk, fitting over a hole in the boiler shell. This plate is held to its place in one of three ways: (1) By a dead weight; (2) by a weight on a lever; (3) by a spring.

The weight or spring is so adjusted that when the steam reaches the desired pressure, the disk is raised from its seat, and the surplus steam escapes through the opening in the shell.

3. Dead-Weight Safety Valve.—The dead-weight form of safety valve, while quite popular in Europe, has not found favor in America, since the high steam pressures now used require an extremely heavy weight. Dead-weight safety valves possess one great advantage over other types: it is difficult to overload them. The weights are so large that it would take a considerable added weight to materially raise the blowing-off pressure, and any added weight could readily be seen by the engineer.

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4. Lever Safety Valves.—Two forms of lever safety valves are shown in Figs. 1 and 2. The valve *V* is held to its seat by the weighted lever *L*. The weight *W* is adjustable along the lever, so that the valve may be set to blow off at various steam pressures.

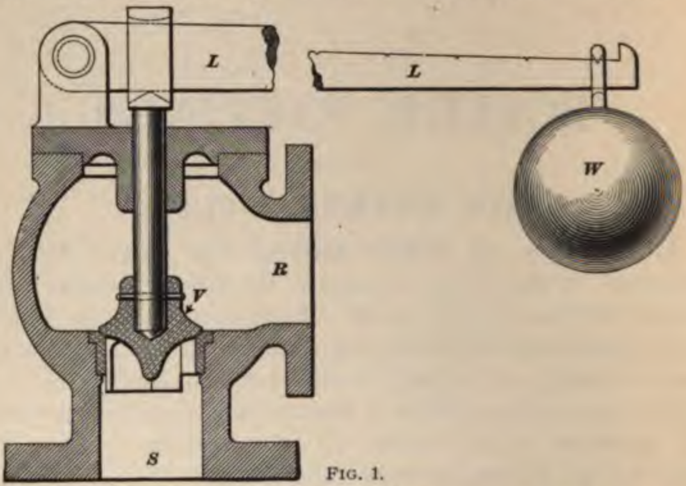

FIG. 1.

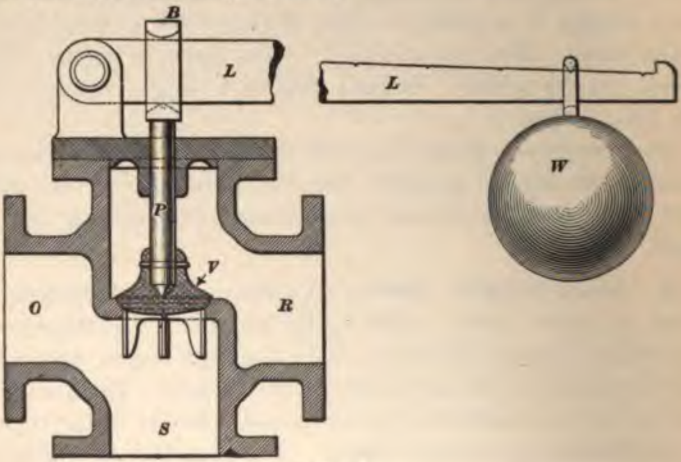

FIG. 2.

The valve shown in Fig. 1 is attached directly to the boiler shell; the steam enters from the boiler at *S* and is discharged through the orifice *R*. The valve shown in Fig. 2 differs from the other in being attached to the supply pipe. The steam passes on its way from the boiler through the passage *S O*. When the pressure rises above the normal pressure, the valve *V* opens and the steam escapes into the air through the opening *R*.

The lever *L* is usually provided with several notches, each notch corresponding to a certain blow-off pressure. It is plain that the nearer the end of the lever the weight is placed, the higher will be the blow-off pressure.

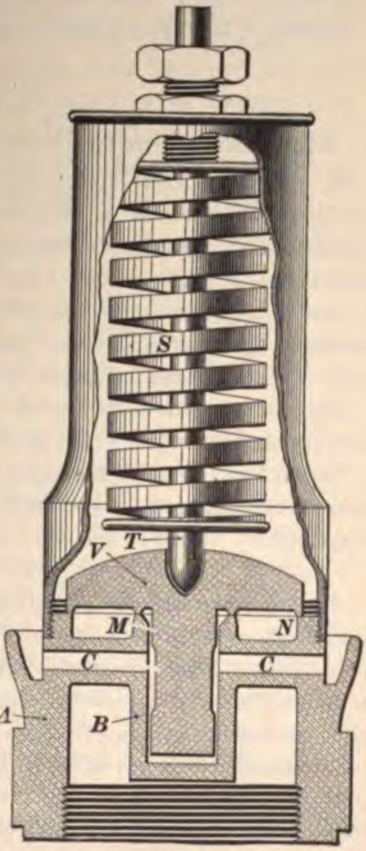

FIG. 3.

5. Spring safety valves are largely used at present, especially on locomotive and marine boilers. The valve is held to its seat by a spring acting either directly on it or on a short lever. The Crosby "pop" safety valve is shown in Fig. 3. The main valve *V* is held down on the two circular seats *M* and *N* by the spring *S* acting on the rod *T*. The outer seat *N* is formed on the body *A* of the valve, while the inner and smaller seat *M* is formed on the upper edge of a cylindrical chamber *B* that is connected to the body *A* by arms containing the passages *C*, *C*. The hollow chamber *B* forms a guide for the valve *V*. Ordinarily, the steam exerts a pressure on the space between *M* and *N*; when the valve rises a little, the steam rushes over the seat *N* into the air and over the seat *M* into the chamber *B*, whence it escapes through the channels *C*, *C*. The channels are, however, not large enough to allow the steam to escape from the chamber as fast as it enters, and hence the pressure in the chamber rises and acts on the area inside the seat *M*. This additional pressure throws the valve wide open and quickly relieves the pressure in the boiler.

In this form of valve the blow-off pressure may be changed by altering the tension of the spring; thus, screwing down the hollow bolt at the top of the spring (Fig. 3) compresses the spring and raises the blow-off pressure.

DIRECTIONS FOR USE AND CARE OF SAFETY VALVES.

6. See that the safety valve is attached directly to the boiler. If there is a stop-valve between the valve and boiler, have it removed or arranged so that it cannot be shut.

Take care that the valve does not become corroded and stick to its seat. It is a good plan to frequently lift the valve from the seat and see whether or not it works freely.

Do not overload the valve or increase the tension of the spring, and take care that it is not done by others.

When the blow-off pressure is fixed, the weights are often locked in position by the boiler inspector and should not be changed.

7. In practice, the position of the weight on the lever is usually found by trial in preference to finding it by calculation. Most safety-valve levers are notched and have figures stamped below the notch, which are supposed to represent the pressure per square inch at which the valve will blow off when the weight rests in the notch. However, since it may be possible that the notches have not been correctly located, it is good practice to check the graduation by an actual trial. To do so, get up steam on the boiler, and as soon as the steam gauge shows the blow-off pressure, shift the weight until the valve just commences to blow off. Then fasten or lock the weight, if possible, so it may not be shifted accidentally. Before adjusting the position of the weight, make sure that all parts of the valve work freely and that the steam gauge is correct.

8. After adjustment, the valve should occasionally be tested by comparing its blowing-off point with the pressure shown by the steam gauge. If the steam gauge indicates a higher pressure, it shows one of two things: either the steam gauge has become impaired or the valve is out of order. If there is reason to suspect the steam gauge, have it tested. At any rate, however, in order to be on the safe side, the steam gauge may be assumed to be correct and the valve then examined to see if everything works freely. If found so, and the weight is still at the same mark, it is reasonable to conclude that the gauge is out of order.

9. It is common practice in some localities to connect a pipe to the blow-off side of the safety valve for the purpose of carrying the steam blown off out of the boiler room. Such an escape pipe, while harmless enough when of sufficient area and kept well drained, may become a source of danger if no provision is made for draining it constantly. Instances are not rare where, owing to the absence of a drain pipe, the escape pipe has become filled with water, thus adding greatly to the external force on the valve and rendering it inoperative for the blow-off pressure for which it was set. When an escape pipe is used at all, it should not be of smaller diameter than the valve, and should have a drain pipe of ample size at its lowest point. No cock or valve should under any circumstances be placed in this drain pipe. Many engineers will not allow an escape pipe to be used under any consideration, claiming that with it, it is frequently impossible to know by sound whether the safety valve is blowing off. Safety valves should in all cases be so fitted that it is an *absolute* impossibility to shut off connection between the boiler and its safety valve.

CALCULATIONS RELATING TO SAFETY VALVES.

10. General Principles.—No safety valve can open without a slight increase of pressure above that for which it is set, since, in order to lift the valve, the pressure on the under side of the valve, which we may call the internal or upward force, must exceed the external or downward force on the valve plus the friction of the mechanism of the valve. If the internal and the external forces upon the valve are equal, the valve will be in equilibrium (balanced), and an increase of the internal force will cause it to open. A safety valve will not close until the pressure has been reduced somewhat below the pressure at which the valve opened.

The point at which a safety valve will blow off depends on the external force on the valve. To be in equilibrium, the external load exerting a downward pressure on the valve must be equal to the internal force exerting an upward pressure on the under face of the valve. Evidently the upward pressure is equal to the area of the valve multiplied by the pressure per unit of area.

Whenever the word "pressure" is used in relation to calculations pertaining to safety valves, the **gauge pressure** is meant, unless otherwise stated.

NOTE.—The area of a safety valve is that part that receives the steam pressure when the valve is seated.

Suppose that we have a dead-weight safety valve having a diameter of 4 inches and an external load or force consisting of the valve and stem, the supporting plate, and the weights, equal to 815.8 pounds; it is desired to know the pressure at which the valve will open. Since the internal and external forces must balance, it is evident that $815.8 = 4^2 \times .7854 \times$ steam pressure in pounds per square inch.

From this we get $\frac{815.8}{4^2 \times .7854} = 65$ pounds per square inch, nearly, the pressure at which the valve is about to open.

11. In the lever safety valve shown in Fig. 2, the external load depends on the position of the weight W on the lever L.

Here the same general law holds good; the external and the internal forces must be equal before the valve is about to open. The internal force, as stated before, is the area of the valve times the steam pressure. The downward force on the valve may be found as follows: Suppose we place the weight *P*, Fig. 4, weighing 100 pounds, directly on top of the valve stem *C*. Evidently the downward force is now equal to the weight of the weight *P*. Suppose now that the weight is removed to the position shown in the figure, the weight's distance *d* from the fulcrum being 6 times greater than the distance *a* from the fulcrum to the center line of the valve. Evidently the effect of the weight on the valve stem will now be 6 times greater; that is, the downward force will be 6 × 100 = 600 pounds. Hence, to find the downward force, we divide the distance *d* by the distance *a* and multiply the quotient by the weight of the weight *P*.

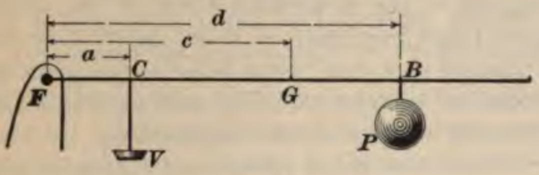

FIG. 4.

As the valve and stem have a certain weight, the external force is increased an amount equal to that of the weight of the valve and stem in pounds. Furthermore, the lever has a certain weight, and this, acting at the center of gravity of the lever, adds a certain amount to the downward force. This amount is equal to the product of the distance from the fulcrum of the lever to its center of gravity and the weight of the lever, divided by the distance from the fulcrum to the center line of the valve.

12. The distance to the center of gravity of the lever may be found by balancing the lever on a knife edg measuring the distance from the center of the fulcrum to the knife edge. If this should not be feasible, the center of gravity must be found by calculation. In engineers' examinations, the lever is usually given as straight and parallel, in which case the distance from the fulcrum to the center of gravity of the lever should be taken as equal to one-half the length of the lever.

The amount of the downward force on the valve due to the weight of the lever may be found directly by attaching a spring balance by a cord to the lever at the point at which it acts upon the valve stem. The spring balance will indicate the correct downward force in pounds.

Now, to have the valve balance, the area of the valve times the steam pressure (the upward force) must equal the weight times the distance from the fulcrum to the weight divided by the distance from the fulcrum to the center line of the valve; to this downward force must be added the additional downward force due to the weight of the valve, stem, and lever (the external force).

13. Illustrative Example.—How to find the pressure per square inch at which a safety valve is about to blow off may best be explained by the following example: Suppose that we have a safety valve of the following dimensions: Let the area of the valve be 12.566 square inches; the distance from the fulcrum to the center line of the valve, 4 inches; the weight is to weigh 135.2 pounds; the length of the lever is to be 36 inches; the weight of the valve and stem, 9.2 pounds; and the downward force due to the weight of the lever, as found by one of the three methods previously explained, 150 pounds. From what has been explained above, it should be clear that the valve balances, or is in equilibrium, if the steam pressure $\times$ 12.566 $= 135.2 \times 36 \div 4 + 9.2 + 150$. That is, the steam pressure $\times$ 12.566 $= 1{,}376$.

From arithmetic, it should be plain that the steam pressure $= \frac{1{,}376}{12.566} = 109.5$ pounds per square inch.

14. Rules for Safety-Valve Calculations.—

Let A = area of valve in square inches;
D = distance from center line of valve to fulcrum, measured in inches;
L = distance of weight from fulcrum in inches;
P = steam pressure in pounds per square inch;
W = weight of the weight on lever in pounds;
w = weight of valve and stem in pounds plus the downward pressure due to weight of lever.

Rule 1.—*To find the pressure at which a safety valve is about to blow off, multiply the weight by the length of the lever and divide this product by the distance from the fulcrum to the center line of the valve. To the quotient add the downward pressure on the valve due to the weight of the valve, stem, and lever, and divide the sum by the area of the valve.*

Or,

$$P = \frac{\frac{WL}{D} + w}{A}.$$

Example.—The area of a lever safety valve is 11 square inches; the distance from the center line of the valve to the fulcrum, 4½ inches; the distance of the weight from the fulcrum, 35 inches; its weight, 125 pounds; the weight of valve and stem plus the downward pressure due to the weight of the lever equals 137 pounds. Find the pressure per square inch at which the valve is about to open.

Solution.—Applying rule 1, we have

$$P = \frac{\frac{125 \times 35}{4.5} + 137}{11} = 100.8 \text{ lb. per sq. in.} \quad \text{Ans.}$$

To explain how to find where a given weight must be placed on the lever in order that the safety valve may be about to blow off at a given pressure, we will take the example previously made use of. The pressure was found to be 109.5 pounds per square inch; hence, the total upward force is 109.5 × 12.566 = 1,375.977, say 1,376 pounds. This force is partially balanced by the weight of the valve and stem and the downward force due to the weight of the lever. Consequently, the total upward force = 1,376 − (150 + 9.2) = 1,216.8 pounds, is to be balanced by the downward force.

As the downward force, as previously explained, is the weight times the length of the lever divided by the distance from the fulcrum to the center line of the valve, it should be plain that the valve is in equilibrium again, if $1{,}216.8 = \frac{135.2 \times \text{the lever}}{4}$. That is, $1{,}216.8 = 33.8 \times$ the lever.

Hence, length of lever $= \frac{1{,}216.8}{33.8} = 36$ inches.

Rule 2.—*To find the distance from the fulcrum to where the weight must act in order to have the valve blow off at a given pressure, subtract the downward force due to the weight of the valve, stem, and lever, from the product of the area and the steam pressure. Multiply the remainder by the distance from the fulcrum to the center line of the valve and divide this product by the weight.*

Or,

$$L = \frac{(A\,P - w)\,D}{W}.$$

EXAMPLE.—At what distance from the fulcrum must a weight of 150 pounds act in order that the valve may be about to blow off at 100 pounds pressure, the diameter of the valve being 3¾ inches; the distance from the fulcrum to the center line of the valve 4½ inches; and the downward force due to the weight of valve, stem, and lever 125 pounds?

SOLUTION.—Applying rule **2**, we get, since area $= (3\tfrac{3}{4})^2 \times .7854 = 11.04$ square inches,

$$L = \frac{(11.04 \times 100 - 125) \times 4.5}{150} = 29.37 \text{ in. Ans.}$$

15. It is desired to find the weight that must be placed on a lever to have the valve blow off at a given pressure:

Using the same example as in the other explanations, the unbalanced upward force, as previously found, is 1,216.8 pounds.

The valve balances if $1{,}216.8 = \frac{\text{weight} \times 36}{4}$.

That is, $1{,}216.8 = \text{weight} \times 9$, and the weight $= \frac{1{,}216.8}{9} = 135.2$ pounds.

Rule 3.—*To find the weight that must act on a lever at a given distance from the fulcrum so that the valve is about to blow off at a given pressure, subtract the downward* *force due to the weight of the valve, stem, and lever from the product of the area and the steam pressure. Multiply the remainder by the distance from the fulcrum to the center line of the valve, and divide this product by the distance from the fulcrum at which the weight is to act.*

Or, $$W = \frac{(A\,P - w)\,D}{L}.$$

Example.—A safety valve has the following dimensions: Area of the valve, 15.7 square inches; length of lever, 48 inches; distance from fulcrum to center line of the valve, 5 inches; the downward force due to the weight of the valve, stem, and lever is 182 pounds. Find the weight if the valve is about to blow off at 64 pounds pressure.

Solution.—Applying rule **3**, we get

$$W = \frac{(15.7 \times 64 - 182) \times 5}{48} = 85.71 \text{ lb. Ans.}$$

Note.—The student should thoroughly familiarize himself with the calculations pertaining to lever safety valves, as a candidate for an engineer's license is usually asked to solve safety-valve problems similar to those given here.

Spring-loaded and pop safety valves are adjusted under pressure by comparison with an accurate steam gauge. No rules can be given by which to calculate the point at which they will blow off.

EXAMPLES FOR PRACTICE.

1. A dead-weight safety valve having an area of 12 square inches is to be on the point of blowing off at 75 pounds pressure, absolute; find the weight. Ans. 723.6 lb.

2. At what pressure will a safety valve of the following dimensions blow off: Area of valve, 10 square inches; distance from the valve to the fulcrum, 3 inches; length of lever (the distance from the fulcrum to the point where the weight acts), 30 inches; weight of the weight, 83.1 pounds; weight of valve and stem, 5 pounds; weight of lever, 12 pounds; total length of lever, 32 inches? The lever is straight and parallel. Ans. 90 lb.

3. Suppose all the quantities to remain the same as in the last example, except that the valve is to blow off at 75 pounds pressure. At what distance from the fulcrum must the weight be placed? Ans. 24.58 in.

4. All quantities remaining the same as in example 3, except that the valve is to blow off at 82 pounds pressure, find the weight that must be placed on the lever. Ans. 75.1 lb.

THE STEAM GAUGE.

16. Construction.—The **steam gauge** indicates the pressure of the steam contained in the boiler.

The most common form is the **Bourdon pressure gauge,** Fig. 5. It consists of a tube *a* of elliptical cross-section, which is filled with water and connected at *b* with a pipe leading to the boiler. The two ends *c* are closed and are attached to a link, which is in turn connected with a quadrant *e*; this quadrant gears with a pinion *f* on the axis of the index pointer *g*. When the water contained in the elliptical tube is subjected to pressure, the tube tends to take a circular form, and, as a whole, straightens out, throwing out the free ends a distance proportional to the pressure. The movement of the free ends is transmitted to the pointer by the link, rack, and pinion, and the pressure is thus recorded on the graduated dial.

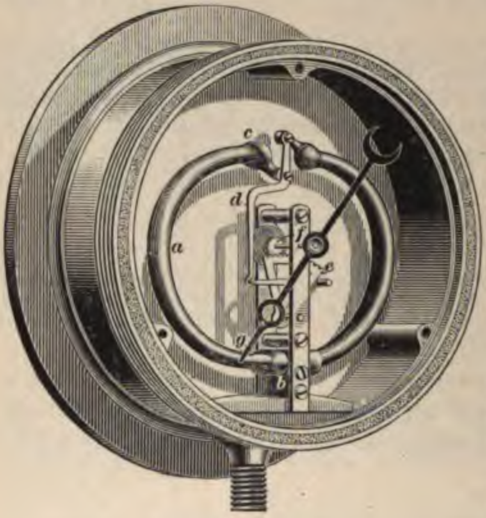

FIG. 5.

17. Methods of Graduation.—Pressure gauges for indicating steam pressure are invariably graduated to indicate pressure *above that of the atmosphere*, in pounds per square inch, and show how much the pressure has been *increased* above the atmospheric pressure. When pressure gauges are used for indicating the pressure in the condenser, they are called **vacuum gauges,** and are invariably graduated to show in inches of mercury how much the pressure has been *decreased* below that of the atmosphere. Then, to find the absolute pressure, the vacuum-gauge reading must be subtracted from 30, and the pressure will then be given in inches of mercury. To obtain the absolute pressure in pounds per square inch, multiply the difference between the gauge reading and 30 by .49. Thus, if the vacuum gauge indicates 25 inches, the absolute pressure in the condenser is $(30 - 25) \times .49 = 2.45$ pounds per square inch.

18. Rule for Absolute Pressure.—The rule just given is entirely correct for normal atmospheric conditions at sea level. Since the pressure of the atmosphere decreases, however, with every increase of altitude, and, furthermore, since the pressure of the atmosphere at the same place is not constant, but varies between certain limits, it is better, if accuracy is desired, to use the following general rule:

Rule 4.—*To find the absolute pressure shown by a vacuum gauge, subtract the vacuum-gauge reading from the reading of the barometer and multiply the difference by .49.*

EXAMPLE.—What is the absolute pressure if the vacuum gauge indicates 19 inches, while the barometer stands at 26 inches?

SOLUTION.—Applying the rule just given, we get

$$(26 - 19) \times .49 = 3.43 \text{ lb. Ans.}$$

19. Compound steam gauges are occasionally met with in which the left-hand part of the dial indicates vacuum in inches of mercury and the right-hand part pounds per square inch *above* the atmospheric pressure. They are usually found attached to the receivers of cross-compound condensing engines.

20. Methods of Connecting Gauge to Boiler.—The gauge should be connected to the boiler in such a manner that it will neither be injured by heat nor indicate a wrong pressure. To prevent injury from heat, a so-called siphon, which may be made as shown at *a* and *b*, Fig. 6, is usually placed between the gauge and the boiler. This siphon in a short time becomes filled with condensed steam that protects the spring of the gauge from the injury the hot steam would cause. Care should be taken not to locate the steam-gauge pipe near the main steam outlet of the boiler, since this may cause the gauge to indicate a lower pressure than really exists. In locating the steam gauge, care must also be taken not to run the connecting pipe in such a manner that the accumulation of water in it will cause an extra pressure to be shown.

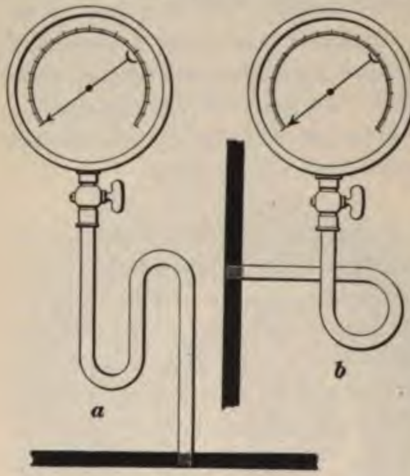

FIG. 6.

GENERAL INSTRUCTIONS FOR USE AND CARE OF STEAM GAUGES.

21. Vibration and Sticking of Pointer.—While the engine is running, it will often be noticed that the pointer of the gauge vibrates so much that the pressure cannot be read. This can be prevented by partially closing the cock below the steam gauge. The greatest of care must be used, however, to prevent an entire closing of the cock. The pointer of a steam gauge will stick occasionally and just when least expected; hence, experienced engineers always jar the gauge a little in order to dislodge any foreign matter that may be preventing movement of the pointer before they accept its indication as correct.

22. Loss of Accuracy.—Steam gauges will lose their accuracy after they have been in use for some time, owing to the spring losing its elasticity or taking a permanent set. In this case the gauge will indicate a pressure higher than the actual pressure in the boiler. This can usually be discovered by the pointer failing to return to the zero mark when there is no pressure in the boiler. If the pressure apparently indicated when there is no pressure be subtracted from the pressure indicated when the boiler is under steam, the correct pressure will be given approximately. However, when a gauge shows a wrong pressure, a new one should be immediately substituted and the old one discarded or sent to the maker for repair.

23. Testing.—When inspecting boilers, the inspectors of boiler-insurance companies or municipal boiler inspectors, usually test all steam gauges in the plant by comparison with an accurate test gauge. The gauge to be tested and the test gauge are both attached to a vessel in which the pressure is raised by means of a small force pump, and the readings of the two gauges are compared at different pressures.

24. Checking.—As previously explained, the safety valve can be checked by means of the steam gauge when the latter is known to be accurate. Conversely, when the safety valve is known to be set correctly, the steam gauge can be checked for the blow-off pressure by watching its indication when the valve just blows off. If a steam gauge shows an error of more than five pounds, it will be condemned by most boiler inspectors. Steam gauges should be taken off at least once a month and the connecting pipe cleared by blowing steam through it. When the gauge is off, see that the hole in the nipple is perfectly clear.

25. Number of Gauges Used.—Good practice demands that one steam gauge should be attached to each boiler where there is more than one boiler used. In some regions, however, it is not uncommon to see one steam gauge do duty for a whole battery of boilers. Such an arrangement has nothing but cheapness to recommend it and is severely condemned by most engineers.

26. Repair.—With some kinds of water the spring of the steam gauge will corrode. Under no circumstances attempt to fix a corroded spring by soldering up the hole or holes. Instead of this, send the gauge to the maker to have a new spring fitted and adjusted. When replacing the gauge after taking it off, make *sure* that the valve in the steam-gauge pipe is opened before going farther and then make sure that the gauge is operative. It has happened in numerous instances in putting up the piping with unions, that the gasket placed between the two parts of the union has been so large that in tightening the nut it has been squeezed out so as to completely stop the hole in the pipe, thus preventing the gauge from showing the pressure.

GAUGE-COCKS AND WATER GAUGES.

GAUGE-COCKS.

27. Purpose and Location.—Gauge-cocks are simple valves or cocks that are attached to the boiler for the purpose of testing the level of the water. The cocks, usually three in number, are placed either on the head or shell or they are attached to the water column. The lowest cock is placed at the lowest level that the water may safely attain and the uppermost cock at the highest desirable level. On opening a cock above the water level, steam will issue forth, and on opening one below the water level, water will appear. Hence, the level may be easily located by opening the cocks in succession. The lowest cock should be located about 3 inches above the lowest water level advisable, which, in case of a return-tubular boiler, would be 3 inches above the upper row of tubes, and in a boiler of the locomotive type about 3 inches above the highest part of the crown sheet.

GLASS GAUGES.

28. The **gauge glass** is a glass tube whose lower end communicates with the water space of the boiler and whose upper end is in communication with the steam space. Hence, the level of the water in the gauge should be the same as in the boiler. Boilers in good work are provided with both cocks and gauges. Fig. 7 shows a common form of gauge-glass connection. The lower fitting connects with the water space and the upper fitting with the steam space of the boiler. A drip cock is placed at the lower end of the glass for the purpose of draining it. The fittings may be screwed directly into the boiler head. The gauge should be so located that the water will show in the middle of the gauge glass when at its proper level in the boiler.

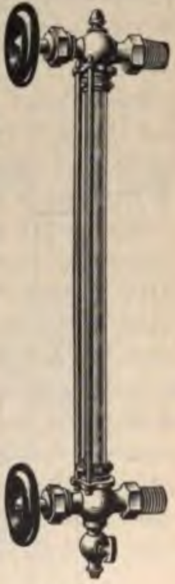

FIG. 7.

WATER COLUMNS.

29. Gauge-cocks and glass water gauges connected directly to the boiler head are open to the objection that the violent ebullition at the surface of the water will cause them to indicate a wrong water level. To overcome this objection, they are frequently placed on a separate fitting known as a **water column,** which consists of a large hollow tube with its ends connecting with the steam and water spaces of the boiler far enough above and below the water level to be out of reach of the violent ebullition of the surface of the water.

30. Fig. 8 shows an arrangement of water column, gauge glass, gauge-cocks, and steam gauge that is recommended by the Hartford Boiler Insurance Company, where *H* is a round cast-iron column whose inside diameter is about 4 inches. The upper end communicates with the steam space of the boiler by means of the pipe connection *I* and the lower end with the water space through the pipe connection *J*. A drip pipe *K* is used for removing the condensed water from the column. The water glass *h* communicates with the column through the connections *L* and *M*. There are three gauge-cocks, *i*, *j*, and *k*. The center line of the lowest one *k* should be located at least 3 inches above the level of the tops of the upper row of tubes in the boiler to insure that they may be always covered with water. The pressure gauge is connected to the pipe *I* by means of the inverted siphon pipe *P*, which answers the same purpose as the bends in Fig. 6.

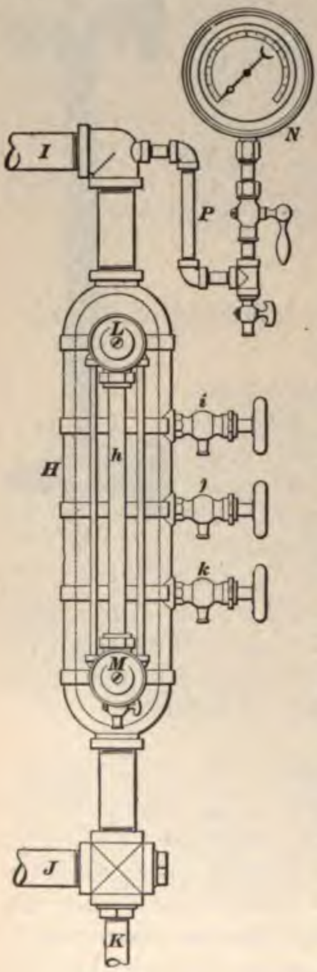

FIG. 8.

USE AND CARE OF GAUGE GLASS AND WATER COLUMN.

31. Too much reliance must not be placed on the gauge glass. If the water is muddy or contains soda, it is liable to foam, and the glass cannot give the true water level. Again, the connections between the glass and boiler may become so filled with incrustation that scarcely any water can enter the gauge. To prevent this, the glass should be blown out frequently. The water gauge and water column should be tested at least once a day. When the water gauge is attached directly to the head, open the drain cock to blow out the glass. Observe if the water returns immediately to its former level when the drain cock is closed. If if it fails to do so, this indicates that the lower fitting is choked with sediment or scale. Should the water fail to leave the glass, or leave it very slowly, it indicates that the upper fitting is choked. When this test shows the gauge to be out of order, it should be repaired at the first possible opportunity, running in the mean time by the gauge-cocks. To remove all temptation to look at the glass, cover it with any material handy. While this may seem an unnecessary precaution, it may be the means of preventing an explosion with the consequent loss of life and property.

32. When water columns are used, they usually have a valve in each connecting pipe. To test both the gauge and the column at the same time, *double shut off* one connection and see if you get the proper fluid through the drain cock. That is, to test the water connection, shut the upper valve of the gauge glass and the valve in the steam connection. Then open the drain cock of the glass water gauge. If water issues in a constant stream, the water connection is clear. Now open the upper valve of the gauge glass and the valve in the steam connection and close the lower gauge-glass valve and the valve in the water connection. If steam flows freely from the gauge-glass drain cock, the steam passages are clear. Close the drain cock again and *open all valves.*

This method of testing is commonly expressed in a somewhat ungrammatical form as follows: *Double shut off what you get, and see if you get the other.*

The student is cautioned against the practice of testing the water column by opening the water-column drain cock only. While this will prove the water column to be clear, it will not prove the glass water gauge.

33. When the water column has no valves in the connecting pipes, test the gauge as if it were connected directly to the head, as previously explained. If the test shows the *water column* to be untrustworthy, haul the fires immediately and shut down until the column is cleared. To prevent the water column from choking up, drain it frequently and do the same with the glass water gauge. Always supplement the draining by the test given. The water gauges are the most important accessories to a steam boiler, and too much care cannot be bestowed on having them absolutely reliable.

34. The pipes for the water column should run as straight as possible and connect directly to the boiler. Under no circumstances whatsoever should these connecting pipes be used for any other purpose or have any other pipe connection in them. When observing the glass water gauge while the boiler is working, note particularly whether the water showing in the glass is stationary or not. If the water level does not fluctuate, or pulsate up and down, as it were, it is an infallible sign that the gauge is out of order. Immediately test the gauge and water column, and if draining them fails to clear them, shut down for repairs.

35. In putting in new glasses that are held in place by rubber packing, care should be used to place the packing evenly, so that the glass will not come in contact with any part of the metal connections; on account of the unequal heat-conducting powers of the glass and metal, the glass is more likely to be broken when thus in contact with the metal than if held free by the packing.

FUSIBLE PLUGS.

36. Construction and Purpose.—In order to give warning of shortness of water in a steam boiler, fusible plugs are used. In many places they are required by law. The ordinary fusible plug in common use is shown in section in Fig. 9. It consists of a brass or iron shell threaded on the outside with a standard pipe thread. The inside is filled with some alloy having a low melting point. As long as the plug is well covered with water, the fusible metal is kept from melting by the comparative coolness of the water; but should the water sink low enough to uncover the top of the plug, the filling quickly melts and allows the steam to rush out; thus giving warning of the shortness of water. The plug shown has a conical filling, the larger end of the filling receiving the steam pressure. The conical form of the filling prevents its being blown out by the steam pressure.

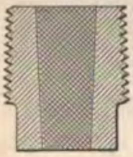

FIG. 9.

37. A good form of fusible plug is shown in Fig. 10. he plug *P* is screwed into the sheet Q, the fusible cap *R* is id on top of it and kept in lace by the nut *U*. A very hin copper cup *S* is placed ver the top of the fusible ap *R* to protect it from ny chemical action of the water. A valuable feature of this style of fusible plug is that when applied to the crown sheet of boilers of the locomotive type, it will give warning of shortness of water before the crown sheet is entirely uncovered, since it extends about 1½ to 2 inches above the sheet.

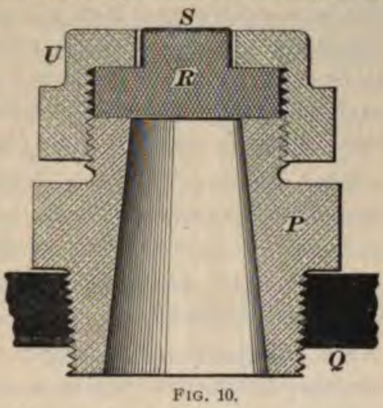

FIG. 10.

38. Location of Plugs.—In horizontal return-tubular boilers, the plug is usually placed in the back head 3 inches above the upper row of tubes. In flue boilers of the two-flue type, one plug is screwed in each flue at its highest point, or in the back head at a level about 2 or 3 inches above the top of the flues. The latter practice is considered the better, since it will give warning of shortness of water before the flues become uncovered. In firebox boilers, the plug is screwed into the highest point of the crown sheet. In vertical boilers, it is usually screwed into one of the tubes about 2 inches below the lowest gauge-cock. In water-tube boilers, it is located usually in the shell of the steam drum. In general, it should be so located that it will prevent, by the warning it gives, the overheating of the parts within the fire-line.

39. Care of Fusible Plugs.—As with other safety devices, dependence can only be placed on a fusible plug when it is given intelligent and reasonable care. It should be removed at least once a month and examined to see that the filling is not covered by hard scale. Instances are not rare when the filling has melted out and the steam been the boiler room under any circumstances without first closing the blow-off cock. The blow-off cock should be opened wide in order to cause a rapid flow through the pipe; this tends to prevent the lodgment of scale in the elbows and other fittings. The usual diameters of blow-off pipes are as follows: 1½-inch pipe for boilers up to 42 inches in diameter, 2-inch pipe for diameters up to 60 inches, and 2½-inch pipe for larger boilers.

VALVES AND COCKS.

47. For the purpose of controlling the flow of fluids through pipes, valves and cocks are universally used. Valves that allow the fluid to flow through them in either direction are divided into two general classes, viz., *globe valves* and *gate valves*.

48. **Globe valves** are made in a variety of forms, following the same general idea of construction. A common form is shown in Fig. 11. Here the fluid enters at *A* and flows out at *B*. The opening in the valve seat is closed by a flat removable disk, which may be renewed when worn so as to leak. Another common construction is shown in Fig. 12. This style of valve is used at the junction of two pipes at a right angle, and hence is

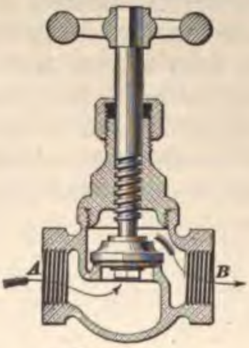

FIG. 11.

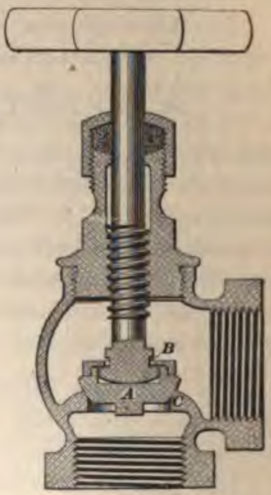

FIG. 12.

termed an *angle valve.* The seat of the particular valve shown is beveled; when worn, it may be made tight again by grinding it in. Globe valves should be attached to the pipes in such a manner that the valve will close against the pressure. This will allow the valve stem to be packed without closing down the plant.

49. Gate Valves.—The waterway through a globe valve is so contorted that it obstructs the flow of a fluid through the valve to some extent. To overcome this objection, gate valves have been designed, a common form of which is shown in Fig. 13. By turning the stem *B*, the wedge-shaped disks *A* and A_1 are moved across the seats *c*, *c*, and the orifice is opened or closed gradually. The disk A_1 has cast on its lower side a projection *D* that rests on a corresponding projection *E* that is cast with the valve body. These two projections form a stop for the disk A_1; when it has come to a stop, a further turning of the stem wedges the two disks apart, pressing them tightly against the seats. A gate valve may be put on to receive the pressure on either side.

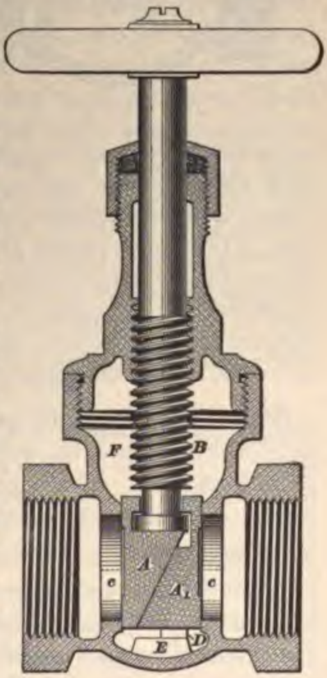

FIG. 13.

50. Check-valves are valves designed to permit the flow of fluids in one direction only and to positively prevent any return flow. The most common form of check-valve is that known as a globe check. It is shown in Fig. 14. The valve *A* is a solid disk of metal ground to the beveled seat *B*. It is guided by the wings *C* and *E* above and below the seat. The fluid passes in the direction of the arrows.

51. An improved form of check-valve, known as a **swing check,** is shown in Fig. 15. The valve disk is attached to an arm that swings on a pin, as shown. The passage of the fluid through this valve is more direct than in the globe check, and the pressure required to open the valve is much less. The fluid passes through the check in the direction shown by the arrows, that is, from *A* toward *B*. In case of a rapid flow, the projection *C* on the end of the arm, to which the valve is attached, strikes against the bottom of the screw *D*, and is thus kept from going too far.

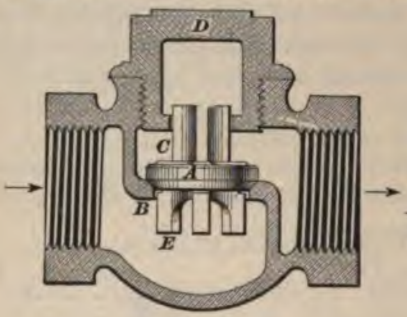

FIG. 14.

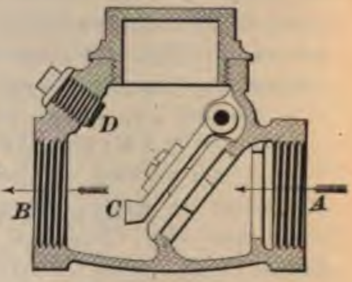

FIG. 15.

52. The two kinds of check-valves illustrated are not very well adapted for working in any other except a horizontal position. If a check-valve must be used in a vertical pipe, one made especially for this purpose should be obtained.

53. **Cocks** are rarely used for any other purpose than the blow-off pipe. Ordinary water-cocks, as used by plumbers, are not well adapted for this purpose; special blow-off cocks are made and can be obtained from all reputable makers. The objection to the ordinary plug cock is its tendency to leak around the bottom and the difficulty of moving the plug after the cock has been closed for some time. To overcome this difficulty, asbestos-packed plug cocks have been designed and are gradually coming into extensive use. These cocks have dovetail grooves cast into the body, into which asbestos is tightly driven. The stos being slightly elastic, it fits snug against the plug, making a tight joint; at the same time, owing to the ll amount of friction, it allows the plug to be turned ly. Since the asbestos is not affected by heat or moist- it is quite durable.

DOME AND STEAM DRUM.

54. **Domes** are placed on cylindrical boilers for the purpose of increasing the steam space, and also for the purpose of drying the steam, the supposition being that the steam will be dried on account of its being farther removed from the water. The hole cut in the shell to give communication between the boiler and dome should be made only large enough to allow a man to pass through, since a large hole materially weakens the shell. The edge of the plate around the hole should be reenforced by a wrought-iron ring riveted to it. The flat top of the dome must be stayed by diagonal braces. Steam domes usually have a diameter equal to one-half the diameter of the boiler, and a height equal to about nine-sixteenths the diameter of the boiler.

55. Boilers are often fitted with a **steam drum** instead of a dome. The steam drum is simply a cylindrical vessel connected to the shell. When several boilers are set so as to form a battery, they are often connected to one drum common to all boilers. When each boiler has its own furnace, there should be a stop-valve between each boiler and the drum to allow the boiler to be taken out of service when required. When the boilers in battery have one furnace common to all of them, no stop-valve should ever be placed in the pipe connections between each boiler and the drum. Where boilers are in battery with separate furnaces, each boiler must have its own safety valve, which should always be so fitted that it cannot be cut off from the boiler under any circumstances.

56. Some boilermakers when fitting a longitudinal steam drum to a boiler will attach it by two nozzles. Many engineers object to this method, since with an unequal expansion of the boiler and drum, which is quite likely to occur, the joints of the nozzles will become leaky, owing to the strains to which they are subjected. It is now the rule in good work to use one nozzle only. When the steam drum is used for a single boiler, its diameter may be made equal to one-half the diameter of the boiler, and its length equal to the diameter of the boiler. Where one steam drum is common to several boilers, its diameter is usually made equal to half the diameter of the boiler, and its length equal to the horizontal outside-to-outside measurement over the several boiler shells.

57. The strength of steam drums may be determined by the rules governing the strength of boiler shells. They require just as rigid inspection as the boiler itself.

THE DRY PIPE.

58. Stationary boilers are often fitted with a **dry pipe.** This consists of a pipe closed on both ends, located near the top of the shell inside of the boiler, and connected in any suitable manner to the steam pipe. The upper half of the pipe is either perforated or provided with a number of slots through which the steam enters. The supposition is that by this means most of the entrained water will be separated from the steam, the water flowing into the water space through small holes in the bottom of the dry pipe. The combined area of the perforations should be about equal to the area of the stop-valve.

THE MUD DRUM.

59. **Mud drums** are occasionally attached to stationary boilers for the purpose of providing a quiet place for the collection of mud and sediment in mechanical suspension in the feedwater, which is then introduced in the mud drum. It is located underneath the boiler and at the rear end, being connected to the boiler by a suitable nozzle, usually of cast iron. Where several boilers are set in battery, they are sometimes connected to a common mud drum. This practice is permissible when the whole battery is used at once. When so fitted, none of the boilers can be temporarily taken out of service unless each nozzle is provided with a stop-valve. Owing to the difficulty of protecting the valve from the fire, this is rarely if ever done. This consideration limits the use of a common mud drum to cases where all the boilers are worked together. When a mud drum is fitted, the blow-off should be attached to it and the sediment collected in the drum frequently blown out.

MANHOLES AND HANDHOLES.

60. For the purpose of allowing the inside of the boiler to be examined, cleaned, and repaired, holes closed by suitable covers are cut into the head or shell. When of sufficient size to admit a man, they are called *manholes;* otherwise, *handholes.*

61. The Manhole.—A common construction of a manhole and its cover is shown in Fig. 16. An elliptical hole is

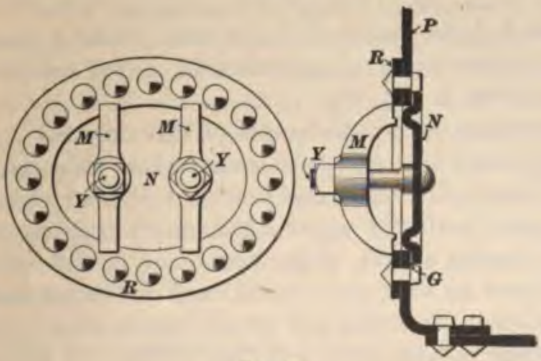

FIG. 16.

cut into the head or shell of the boiler. A wrought-iron or steel ring *R*, called a **compensation ring,** is riveted to the plate *P*, generally on the outside, for the purpose of strengthening the plate, which is weakened considerably by the cutting of such a large hole through it. A cover *N* made of wrought iron, cast iron, or steel is fitted to the hole, inside of the boiler, and is provided with two studs *Y*, *Y* riveted to it. This cover is flanged and overlaps the edges of the plate about 1 inch or more all around its perimeter. A yoke *M* is slipped over each stud, its two extremities resting on the compensation ring. A ring *G*, or *gasket*, as it is commonly called, made of sheet rubber or any other pliable waterproof material, is placed between the plate and the cover and serves to make a water-tight joint.

62. Of late years it has become quite generally the practice to flange the head inwards and face its edge, thus doing away with the necessity for the compensation ring. When the manhole is in the shell, in the best modern practice, a flanged compensation ring is riveted to the inside of the shell, as shown in Fig. 17.

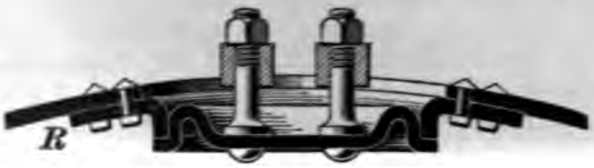

FIG. 17.

In the design shown, the edges of the ring and cover are faced and carefully fitted to each other, thus making a metallic joint. Owing to the practical difficulty of making such a joint perfectly water-tight, most engineers would prefer to place a gasket, either fibrous or metallic, between the cover and its seat, even when both are faced and fitted to each other. Manholes are usually made about 11 inches by 15 inches in the clear. If any smaller, it is a rather difficult matter for a man to get through them.

63. The Handhole.—Handholes are placed in boilers whose construction does not permit the entrance of a man, as, for example, in vertical boilers. They are also placed in other boilers in convenient positions; thus, in boilers of the locomotive type they are usually placed in the corners of the water legs, and in horizontal return-tubular boilers are often found in the heads below the tubes. The handhole is a convenient place to rake out sediment and scale and to admit a hose for the purpose of washing out the boiler. The handhole and its cover are constructed very much like a manhole and cover; the handhole being smaller, requires but one yoke and bolt to close up the cover.

64. Manholes and handholes are made elliptical to allow the cover to be passed through the hole. The smallest diameter of the cover is somewhat less than the largest diameter of the manhole, and thus allows the cover to pass freely through the manhole. It is then turned one-quarter around inside the boiler, the gasket placed on the flange, and put in position.

65. When using sheet rubber or other fibrous gaskets, it is advisable to give them a good coating of plumbago on both sides. This will prevent their sticking to the cover and seat and allow them to be readily removed. It is rarely advisable to use the same gasket again when replacing the cover; it will usually have become carbonized by the heat and thus be too hard to make a tight joint, no matter how hard the nuts are screwed up. When the cover has been replaced with a new fibrous gasket, it is well to examine it again after steam has been gotten up and tighten up the nuts once more. A plentiful supply of graphite (plumbago) smeared on the threads of the bolts before the cover is replaced will allow the nut to be readily removed at the next examination.

66. When a manhole or handhole gasket blows out, as will happen if the work of replacing the cover has been carelessly done or the gasket cut too large, about the only thing that can be done is to haul the fire, blow out the boiler after the steam has gone down, and make the joint over again.

67. Before taking off a manhole or handhole cover, immediately after the boiler has cooled down, it is advisable to raise the safety valve or open a valve or gauge-cock so as to break the vacuum that may have been formed by the condensation of the steam remaining in the boiler. If this precaution is neglected, it may result in serious injury. While it cannot be truthfully stated that a vacuum will *always* form, instances are on record where this has happened and the cover been forced inwards by the external air pressure.

LOW-WATER ALARMS.

68. The object of the device called a **low-water alarm** is to give warning of low water in the boiler by the automatic sounding of a whistle. This object may be attained by the melting of a fusible plug or by the use of a float connected to the whistle valve. Other means, such as electrical devices and mechanical devices, using the difference in expansion of different metals for actuating the whistle valve, have been used occasionally, but have not come into extensive use, probably on account of being too delicate.

69. **Fusible-plug alarms** possess the advantage of cheapness, but they are very liable to become inoperative because of becoming incrusted with scale. If such an alarm is used, it should be cleaned once a month and the fusible plugs renewed at least every six months. When continually exposed to heat, the alloy of which fusible plugs are composed seems to deteriorate and become non-fusible, hence the recommendation to renew them occasionally.

70. Probably the great majority of alarms belong to the class using a float. They are often arranged to indicate both low and high water. A representative device of this class, known as the **Reliance high- and low-water alarm,** is shown in Fig. 18.

As shown in the figure, the device consists of two hollow floats *a*, *b* that are suspended from the bell-cranks *c*, *d*. To the short arm of each bell-crank is attached the valve stem of a small valve, there being one valve for each float. These valves serve to put the steam space of the water column in communication with the alarm whistle *e*. In this particular design of water column a sediment chamber *f* is formed at the bottom of the column that collects all foreign matter that settles from the water. The water-column drain is connected to the settling chamber.

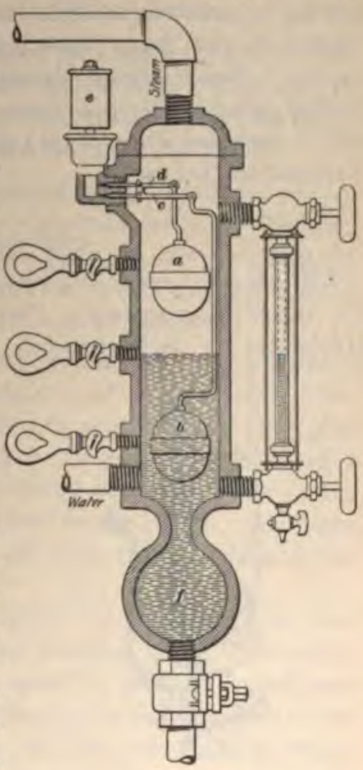

FIG. 18.

71. The operation of the alarm is as follows: when the water is at its proper level, the float *b* is surrounded by water and, being hollow, is pressed upwards. Being connected to the long arm of the bell-crank *c*, this upward pressure keeps the upper whistle valve closed. Let the water become low in the column so as to begin to uncover the float. Then, the upward pressure due to the buoyant effect of the water gradually diminishes and finally will become so small that the float will descend, thus opening the upper whistle valve and sounding the alarm. The high-water alarm float *a* keeps the lower whistle valve closed by the weight of the float. When the water rises, the float is carried upwards, the lower whistle valve is opened, and the alarm sounded.

While water alarms of all makes are perfectly reliable when in good working order, too much dependence should not be placed on them, since, like many safety devices, they will become inoperative with long use. Float-operated alarms become inoperative through the collapsing and corrosion of the floats and the choking up of the whistle valves. Hence, these parts must occasionally be carefully looked after. The floats should frequently be examined to see if they are water-tight, since the working of the alarm depends on this fact.

THE WHISTLE.

72. Nearly every steam plant is provided with a whistle for signaling purposes. Two of the most common constructions are shown in Figs. 19 and 20. The bell, or upper portion, is a hollow cylinder closed at the top and open at the bottom, and is held in position by a stud that passes through the center and is secured at the upper end by means of a screw and jam nut. The hollow base has a narrow circular orifice that communicates with the steam pipe and valve. As the steam rushes out of the orifice in an upward direction, toward the mouth of the bell, it slightly compresses the air contained in the bell. The air being elastic will not retain a fixed or stationary position, but will slightly spring back toward the inrushing steam, where it is again forced back in a compressed state, causing a vibration

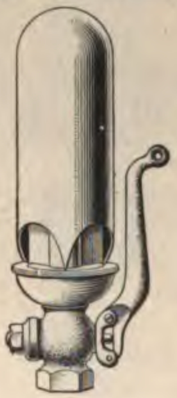

FIG. 19.

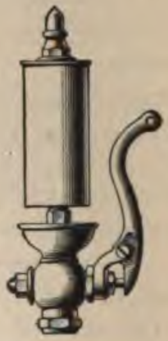

FIG. 20.

of the air and steam. These vibrations continue as long as steam is permitted to flow and are communicated to the surrounding atmosphere, thus producing sound.

73. The tone may be changed to a higher pitch by lowering, or to a lower pitch by raising, the bell. This may be done by loosening the jam nut and turning the bell up or down, after which the nut should be again tightened.

74. Whistles are also constructed to produce two or more tones of different pitch simultaneously by dividing the bell into two or more cell-like parts, as shown in Fig. 19. Each apartment produces a different tone, and when these tones chord perfectly, the effect is quite pleasing.

75. In manufacturing establishments the whistle is usually located on the roof; that is, at a considerable distance above the boiler. In order to prevent this long pipe becoming filled with water, it is advisable to fit a small drain pipe and valve directly above the stop-valve in the whistle pipe, which is placed close to the boiler. At night the steam may then be shut off from the whistle and the drain valve opened.

When no separate valve is fitted to the whistle to shut off the steam, the blowing of the whistle, due to an accident to the whistle valve, may be stopped by pushing a stick into the bell; if this is not feasible, due to the construction of the whistle, stuff cotton waste into the bell, using a long stick.

FEEDPIPING.

76. The pipe system through which a boiler or boiler plant receives its water supply may be divided into two parts: the *external system* and the *internal system.*

The external system comprises the piping required to take the feedwater from its source of supply and to deliver it at the boiler. The internal system consists of the pipes leading from the outside of the boiler to the point of delivery.

77. The **external feed system** comprises the suction pipe of the feed-pump or injector and the delivery pipes o feedpipes that deliver and distribute the water to the different boilers. As to the arrangement of the suction pipes, they should be as short and free from bends as it is possible to make them, especially when the water must be lifted some distance from a well or similar source of supply. In general, it is very difficult to lift water to a greater height than 24 feet at sea level, unless the pump is in excellent condition; if the water must be lifted higher, it is usually better to locate the pump farther down, excavating for it, if necessary. The suction pipes should also be perfectly airtight. When the feedwater is taken from a city water supply, it usually comes to the pump or injector under some pressure; the feed apparatus can then be located where most convenient.

78. The **arrangement of the feedpipes** naturally depends on the number of boilers to be supplied by the feed apparatus and on the extent to which the pump or injector is required to supply water to any one or all of several boilers.

79. In Fig. 21 is shown an ordinary method of arranging the feedpipes where two boilers are supplied by the same pump. The main pipe *P P* running along the front of the boilers receives the feedwater discharged from the pump.

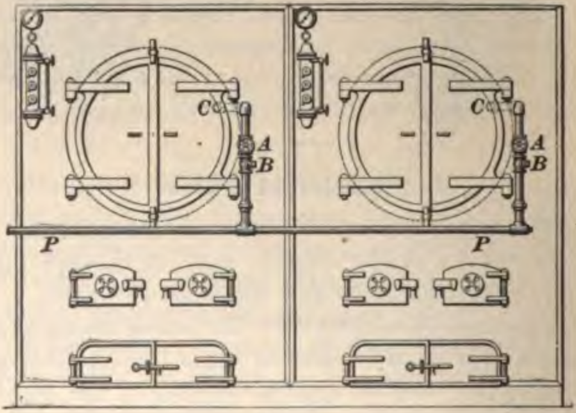

FIG. 21.

Each boiler is supplied by a branch from the pipe *P* entering the front head *C*. Each of these branches is provided with a globe valve *A* and a check-valve *B*. The globe valve shuts off the water from the boiler, while the check-valve allows the water to enter when the globe valve is open, but prevents its return.

80. The globe valve should always be placed nearest the boiler, thus allowing the check-valve to be examined and repaired without shutting down the boiler. With the arrangement of feedpiping shown, the feedwater can be delivered simultaneously to both boilers or to either boiler separately.

81. An arrangement of feedpiping for a plant having six boilers in two batteries with two independent feed-pumps is shown in diagrammatic form in Fig. 22. Both of the feed-pumps shown at *A* and *B* are connected to the main feedpipe *M*. This pipe has six branches, as *D*, *D*, one for each boiler. Each branch pipe has its own globe valve *E* and check-valve *F*. There are two valves in the main feedpipe, one between each pump and the nearest branch pipe. With this arrangement, either or both pumps may be used for any or all boilers. Thus, if it is desired to use pump *A* for all boilers, the valve in the main feedpipe near this pump is opened and the valve near the pump *B* is closed. The pump *A* will then deliver into any or all of the six

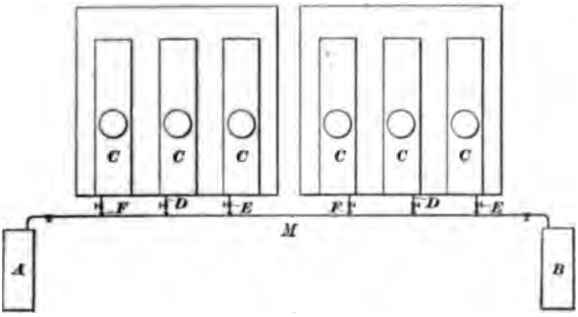

FIG. 22.

boilers, depending on the manipulation of the globe valves in the branch pipes.

82. When the feedwater goes through a feedwater heater before entering the boilers, it is usually advisable to provide by-pass connections, so that in case of accident to the heater, it may be cut out of service without interference with the feeding. In many plants the entire feed system is fitted in duplicate, in order to be prepared for emergencies. One system may then be supplied by injectors and the other by pumps.

83. The **internal feed system** is arranged in various ways. Its purpose is twofold: (1) to conduct the water to the proper point of discharge in the boiler; (2) to heat the relatively cold feedwater to nearly the temperature of the water in the boiler. As to the proper point of discharge, authorities differ considerably. Most engineers believe that the water should be discharged into the coolest part of the boiler and should be diffused by delivering it through a perforated pipe. Others discharge the feedwater into the steam space and use some suitable spraying device to break the entering stream into spray.

84. When discharging into the water space of horizontal tubular boilers, a common and very satisfactory arrangement is to make the feedpipe enter the front head a little below the water-line and carry it to within a few inches of the rear head. The end of the pipe is closed and a number of holes in the bottom of the pipe discharge the water downwards between the tubes. Or the water may enter through the bottom of the rear head; a horizontal pipe then carries it to within a few inches of the front head. It then passes through a vertical pipe up between the tubes to within a few inches of the water level and then returns to the rear through a horizontal pipe and is discharged downwards between the tubes. With this arrangement, the feedwater will be heated to the same temperature as the water in the boiler.

85. In cylinder boilers the feedwater usually enters the bottom of the front head. In good practice it is then carried to the rear by a horizontal pipe and discharged upwards. In some plants this is not done, however, and the water is discharged directly on the crown sheet. This is considered very poor practice by many engineers, since it will subject the plate exposed to the most intense heat to severe local stresses, which ultimately will strain the metal beyond its elastic limit and cause a rupture. In general, it is the common rule that feedwater should never be discharged on the parts of the boiler exposed to the most intense heat, nor should it be delivered in a solid stream against a plate, and, furthermore, it should be discharged in such a direction as to assist the circulation.

86. In flue boilers the water may be discharged in the same manner as in return-tubular boilers. In vertical boilers it is usually discharged into the water leg at the lowest point, although sometimes it is delivered about 2 feet above the crown sheet. In boilers of the locomotive type it may be delivered into the lower part of the cylindrical part or into the water legs below the grate. In water-tube boilers the builders always determine where to discharge the feedwater, and their advice should be followed.

FURNACE FITTINGS.

87. The **furnace fittings** consist of the *grate* with its supports, the *dead plate*, and the *bridge wall*.

88. The **grate,** which is nearly always made of cast iron, furnishes a support for the fuel to be burned and must be provided with spaces for the admission of air. The spaces and supports are alternate and are distributed evenly all over the grate surface. The combined area of all the supports is usually made nearly equal to the combined area of all the air spaces; in other words, half the grate surface is air space and half serves to support the fuel,

89. The most common type of grate is made up of single bars as *A*, Fig. 23, that are placed side by side in the furnace. The thickness of the lugs cast on the bars determines the width of the open spaces of the grate. It is the general practice to make the thickness across the lugs twice the thickness of the support. For long furnaces the bars are generally made in two lengths of about 3 feet each, with a bearer in the middle of the grate. Long grates are generally set with a downward slope toward the bridge of about $\frac{3}{4}$ inch per foot of length. This facilitates the admission of air to the rear of the grate; it also facilitates cleaning the grate.

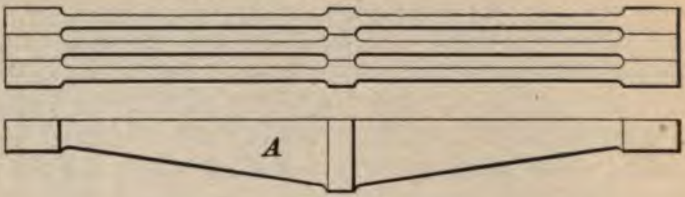

FIG. 23.

90. The width of the air space, and hence the thickness of the grate bar, depends largely on the character of the fuel burned. For the larger sizes of anthracite and bituminous coals, the air space may be from $\frac{5}{8}$ to $\frac{3}{4}$ inch wide, and the grate bar may have the same width. For pea and nut coal, the air space may be from $\frac{3}{8}$ to $\frac{1}{2}$ inch, and for finely divided fuel, like buckwheat coal, rice coal, birdseye coal, culm, and slack, air spaces from $\frac{3}{16}$ to $\frac{3}{8}$ inch may be used. When these small air spaces are used, the grate if made of single bars, like that shown in Fig. 23, must have the bars so thin in proportion to their length that they will warp and twist

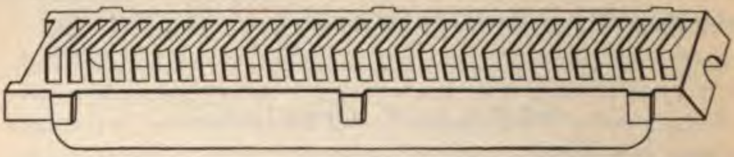

FIG. 24.

nd a large number of the bars will soon break, especially when the rate of combustion is high. To overcome this objectionable feature, the grate bar shown in Fig. 24, and known as the **herringbone** grate bar, was designed, and in many parts of the country it has almost entirely superseded the ordinary grate bar.

91. Owing to the shape of the supports for the fire, they are free to expand and contract; being quite short and of small depth in comparison to the ordinary grate bar, there is very little danger of excessive warping of the supports. In consequence, they will usually far outlast a set of ordinary grate bars. Since there are only a few large bars for the grate, it also is easier to replace a broken bar. Herringbone grate bars can be obtained in a great variety of styles and with different widths of air spaces.

92. In general, a grate bar that is suited for the kind of fuel that is to be burned should be selected. Thus, if finely divided coal is to be burned, a grate bar having small air spaces and supports should be selected, since otherwise a large percentage of the fuel will fall into the ash-pit. On the other hand, for the large sizes of coal, select bars having large air spaces, using the largest air space when caking coals are to be burned. Some varieties of bituminous coal will *cake*, that is, fuse together to a considerable degree, and the ashes and clinkers formed will be of such size that a large part of them cannot pass through the air spaces unless they are large; the grate thus becomes clogged, shutting off the air from the fire. This reduces the rate of combustion and evaporation. When putting in grate bars, they should not be fitted in tightly, but plenty of room should be given to allow them to expand.

93. Shaking Grates.—The greatest objection to stationary grate bars is that with them the furnace door must be kept open for a considerable length of time to allow the fire to be cleaned. Ashes, cinders, and clinkers will collect in the course of time on the grate, shut off the air supply, and

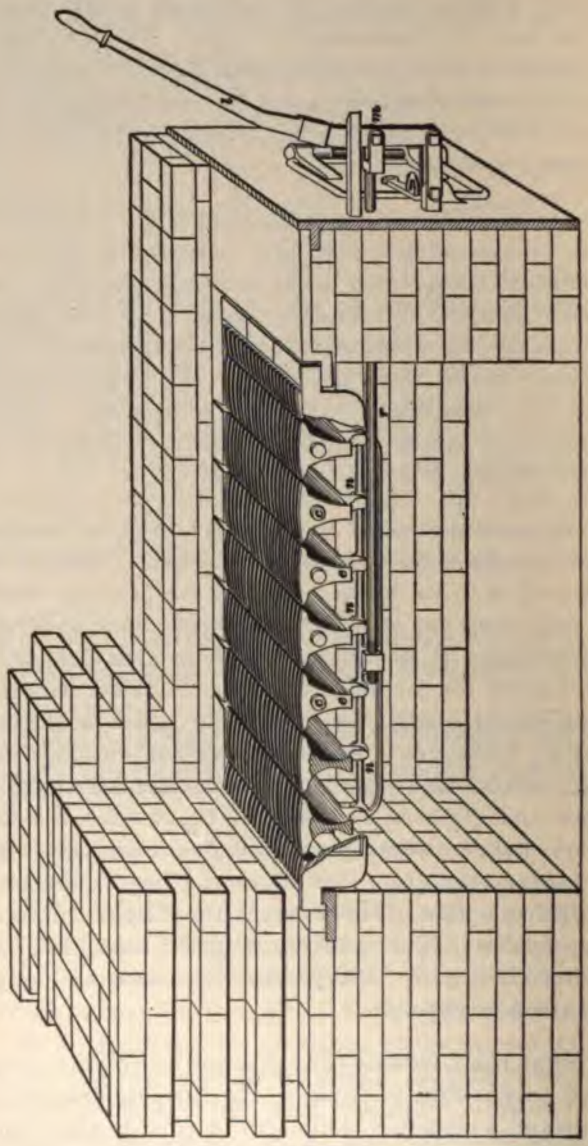

FIG. 25.

thus reduce the amount of steam generated. To restore the fire, it needs to be cleaned. Cleaning fires with a stationary grate is not only a job that severely taxes the fireman, owing to the excessive heat to which he is exposed, but also the inrush of cold air chills the boiler plates, thus producing stresses that in the course of time will crack them. To overcome these objections, grates have been designed that allow the fire to be cleaned without opening the furnace door. This is usually done by giving each grate bar a rocking motion.

94. The McClave shaking grate is shown in Fig. 25. The grate bars *e*, *e*, etc. are supported by trunnions *c*, *c* that fit into bearing bars placed on each side of the grate. A portion of the bearing bar has been removed in order to show the grate bars properly. By working the lever *l* backwards and forwards, the rod *r*, which is connected to the lever *l* by the stub lever *m*, and also with the grate bars at *n*, *n*, etc., transmits the motion of the lever to the grate bars and causes them to rotate to and fro on the trunnions.

The grate operates on the pocket principle; when the grate bars are thrown wide open they form a series of pockets that receive the ashes and clinkers; when the bars are thrown back to their upright position, the ashes are deposited in the ash-pit, and thus a quantity of ashes is removed from the bottom of the fire at each sweep of the lever.

95. This grate has been recently improved so as to allow one-half of the grate to be shaken without disturbing the other half. This is an advantage, inasmuch as the front half of the fire may be in good condition, while the back half may need shaking, and *vice versa*.

This method of cleaning is particularly applicable to anthracite coal fires, since the main body of the fuel is left undisturbed. The grate may also be used for shaking and breaking up the solid bed of fuel, as is necessary in fires of caking bituminous coals. For this purpose the lever vibrated rapidly back and forth through a small arc. The ashes are shaken through the grate and the mass of fuel is broken up. This grate is extensively used for burning the smaller sizes of anthracite, such as the pea and buckwheat sizes, and culm.

96. The **dead plate** is a flat iron plate usually placed just inside the furnace door. Its purpose is to furnish a support for the firebrick lining of the front of the furnace, and with stationary grates it also usually forms the support for the front end of the grate. In using some varieties of coal, it is necessary to place the coal on the dead plate and let it become heated before pushing it on to the grate.

97. The **bridge** is a low wall at the back end of the grate; it forms the rear end of the furnace. The bridge is usually built of firebrick, though in some cases it is made of wrought iron, with an interior water space communicating with the inside of the boiler. It is the office of the bridge to bring the flame in close contact with the heating surface of the boiler. The passage between the bridge and boiler shell should not be too small; its area may be approximately one-sixth the area of the grate. Likewise, the space between the grate and shell should be ample for complete combustion. Professor Thurston advises that the distance between grate and boiler shell should be one-half the diameter of the shell.

DAMPER REGULATORS.

98. In many steam plants it is required that the steam pressure be kept practically uniform. For this purpose **damper regulators** have been designed, which, operating upon a change of the steam pressure in the boiler, automatically control the position of the damper and thus regulate the volume of gases passing into the chimney. This in turn regulates the intensity of the fire and the generation of steam.

Damper regulators may be divided into three general classes:

1. Steam-actuated regulators, where the motion of a diaphragm under variation of steam pressure is transmitted directly through some multiplying device to the damper.

2. Steam-actuated regulators, where the steam in acting on a diaphragm causes a displacement of a valve, which admits steam into a cylinder, the piston of which is connected to a damper.

3. Hydraulic-operated regulators, where the movement of a diaphragm under variation of the steam pressure operates an admission valve, admitting water under pressure to a cylinder, the piston of which is connected to the damper.

99. Damper regulators of the first class are used very little, for while cheap in first cost, the regulation is rather unsatisfactory. Regulators of the second class will regulate very closely. The makers of the Curtis regulator, for instance, guarantee that the motion of the damper from one direction to the other will change with a variation of steam pressure of one-quarter of a pound per square inch, either way, from the point at which it is set to operate.

100. Regulators of the third class will also regulate very closely. Being dependent on water under pressure for their action, their application is limited to places where they can be connected either to a city water service or to a tank sufficiently high above the regulator to give the required pressure. They are sometimes connected directly to the water space of a boiler; while the damper regulator will operate when so connected, this method is open to the objection that it results in a waste of heat that may be quite large.

101. A **Spencer hydraulic damper regulator** is shown in Fig. 26. The diaphragm chamber *b* contains a flexible diaphragm dividing the chamber into two parts. The under part is filled with water which is subjected to the boiler pressure through the steam pipe *d*. The diaphragm tends to move upwards under the influence of the steam pressure, but its upward motion is resisted by the downward force exerted by the weighted lever *c*. The weights on this lever are so adjusted that it will occupy a position midway between its two extreme positions when the steam pressure in the boiler is exactly at the point at which it is to be carried. A secondary lever *f* is hinged at *f'* to the free end of *c*; this secondary lever is fulcrumed at *m*. At *g* the valve stem of the operating valve is attached to it. This valve works inside of the piston closely fitted to the stationary cylinder *h* and serves to admit water under pressure to either side of the piston. The piston rod passes through both heads of the cylinder *h*; at its lower extremity it is connected to the lever *i* pivoted at *i'*, which, through the medium of the connecting-rod *j*, transmits any motion of the piston to the damper.

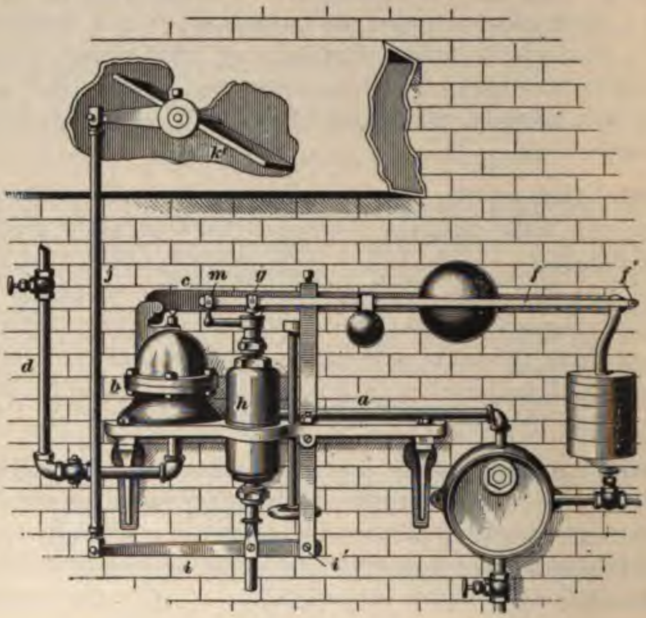

FIG. 26.

Let the steam pressure rise above that for which the damper is set. Then the diaphragm and the free end of the lever *c* move upwards. The lever *f* being connected to *c* at one end, it swings upwards around *m* as a fulcrum; this raises the valve inside of *h* and thus admits water under pressure to the bottom of the piston in *h*. At the same time the valve places the upper side of the cylinder in communication with the water-escape pipe. In consequence thereof, the piston ascends and pulls the lever *i* upwards, which in turn rotates the damper *k*, closing it still farther. Now, as soon as the piston commences to ascend, *m* is moved upwards and the lever *f* swings around *f'* as a fulcrum. This causes the valve in the piston to move downwards in relation to the piston, thus closing the water-supply port and holding the piston in its new position.

When the steam pressure falls below the normal pressure, the levers *c* and *f* descend, and as *f* swings around *m* the valve also descends, placing the upper side of the piston in communication with the water supply and the under side in communication with the water-escape pipe. Then the piston descends and the damper opens. But *f* now swings around *f'*, and thus causes the valve to ascend in relation to the piston, which is then brought to rest.

The cylinder *h* is shown in section in Fig. 27. The piston is made water-tight by the cup-leather packing rings *r*, *r*. The water under pressure enters through the supply pipe *a* and surrounds the piston, entering through a small port into the central valve chamber and then surrounding the central port of the piston valve *t*. Let the valve move upwards. It then uncovers the ports *e'* and *e*. The water under pressure flows through *e'* into the lower part of the cylinder; at the same time the water in the upper parts flows through *e* into the hollow piston rod *s* and out at *l*. The resultant motion of the piston then returns the valve to the central position shown. If the valve descends, it admits the water into the port *e* and allows the water in the lower half of the cylinder to escape through *e'* into *s'*, which, through a by-pass port, communicates with *s*. This by-pass port, owing to the view taken, is not shown. The descent of the piston again returns the valve to its central position.

102. A damper regulator, like other automatic devices, needs intelligent supervision to have it work satisfactorily. The diaphragms will wear out in the course of time and need replacing. Care should be taken in putting it up that everything works freely and that all connections are made as directed by the manufacturer.

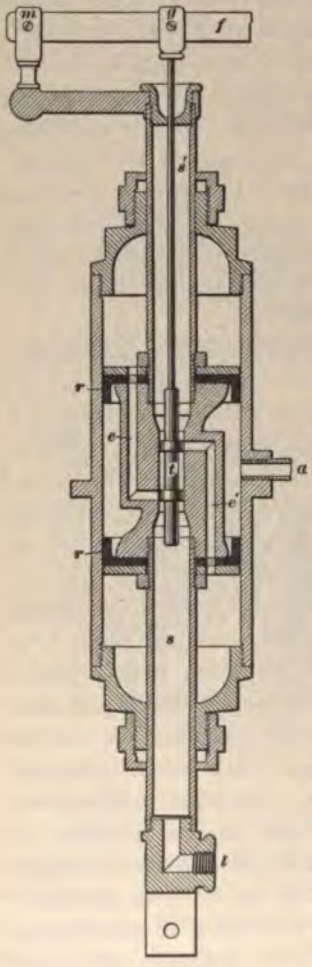

FIG. 27.

103. A damper regulator must not be expected to keep up a steady steam pressure without fire in the furnace; the fire should be carefully tended to. It should always be remembered that while the damper regulator will regulate the air supply to the burning fuel, it will not put fuel into the furnace.

104. Caution.—It is recommended that after shutting down the plant at night, the damper regulator be rendered inoperative. Instances are on record where failure to take this precaution resulted in running up the steam pressure to the blowing-off point during the night. Should the safety valve be out of order, all elements for a boiler explosion are present. If the regulator be left attached to the damper, the drop in the steam pressure due to banked fires will open the damper to its full extent and thus start the fires. To render the regulators inoperative, the steam may be shut off from it at night. It is considered good practice to also drain all water from it at night, especially in winter.

COMBUSTION, FIRING, AND DRAFT.

COMBUSTION.

THEORY OF COMBUSTION.

LAWS OF CHEMICAL COMBINATIONS.

1. Elements and Compounds.—Every body, every mass of matter is either an *element*, a *compound*, or a *mixture*. Iron, silver, sulphur, and oxygen are elements; water, wood, lime, and carbonic acid are compounds.

2. A compound may be decomposed or divided into separate substances. For example, if an electric current is passed through water, the water slowly disappears and two gases are formed. These gases are entirely unlike and neither resembles the water from which it is produced. Likewise, lime can be divided into two other substances—calcium and oxygen. Any substance that can thus be decomposed or divided into other substances is called a **compound.**

3. There are substances, however, that have never been decomposed into other substances. By no known process can sulphur be separated into other substances; likewise, iron, gold, arsenic, and many other substances. Substances that have never been decomposed are called **elements.**

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The elements that will be considered here are the following:

Elements.	Symbols.
Hydrogen	H
Oxygen	O
Nitrogen	N
Carbon	C
Sulphur	S

In referring to an element it is customary to simply use the symbol, which is usually the first letter of the name. Thus, H stands for hydrogen, C for carbon, etc.

4. Chemical Combination.—When two or more elements are brought into contact under favorable circumstances, they will combine and form a new substance that is unlike either of the elements. Of course, the new substance will be a compound. Thus, if carbon and oxygen are brought together at a high temperature, they will combine and form carbon dioxide. Hydrogen and oxygen combine to form water. Hydrogen, nitrogen, and oxygen, when combined in certain proportions, form nitric acid. A given volume of nitrogen and three times that volume of hydrogen combine and form ammonia—a gas that differs greatly from both nitrogen and hydrogen.

5. It is supposed that each molecule of an element, such as hydrogen or oxygen, is composed of two atoms. It is further supposed by chemists that at a given pressure and temperature equal volumes of all *gases*, whether simple or compound, contain the same number of molecules. Thus, a cubic foot of hydrogen, a cubic foot of air, a cubic foot of steam, all contain the same number of molecules at the same temperature and pressure.

Suppose, now, that a cubic foot of hydrogen gas is allowed to come into contact with a cubic foot of *chlorine* gas (symbol, Cl). The mixture is exposed to heat or light and the gases combine. The process of combination is explained as follows: There is a certain attraction or affinity between the hydrogen atoms and the chlorine atoms. Under the influence of heat or light this attraction becomes so strong that the two atoms composing the molecule of hydrogen are torn apart. Likewise, the atoms composing a molecule of chlorine separate. Each atom of chlorine seizes upon an atom of hydrogen and forms a molecule of an entirely new gas; viz., hydrochloric-acid gas. Since each atom of chlorine takes *one* atom of hydrogen, it is plain that the number of molecules of each gas must be the same. In other words, 1 cubic foot of chlorine requires 1 cubic foot of hydrogen to combine with it; these gases cannot be made to combine in any other proportion. For example, if 3 cubic feet of chlorine were placed in contact with 2 cubic feet of hydrogen, 4 cubic feet of hydrochloric-acid gas would be formed, and the extra cubic foot of chlorine would still remain chlorine. The symbol for hydrochloric-acid gas is HCl.

Suppose, now, that hydrogen and oxygen are placed in contact and heated. They will combine and form steam (or water); but it will be found that each atom of oxygen seizes 2 atoms of hydrogen to form a molecule of water, and therefore the volume of hydrogen must be double the volume of the oxygen with which it combines. This is shown by the symbol for water, which is H_2O; that is, a molecule of water is composed of 2 atoms of hydrogen to 1 of oxygen. Similarly, the symbol for ammonia is NH_3; that is, 3 atoms of hydrogen to 1 of nitrogen. Again, hydrogen and carbon form a compound; each atom of carbon seizes 4 atoms of hydrogen and forms a molecule of marsh gas. The symbol for marsh gas is, therefore, CH_4.

6. The symbol of any compound indicates how the atoms of the elements combine to form the compound. Thus, the symbol for water, H_2O, shows that 2 atoms of hydrogen and 1 of oxygen unite to form a molecule of water. The symbol H_2SO_4 (sulphuric acid) shows that 1 molecule of the sulphuric acid contains 2 atoms of hydrogen, 1 of sulphur, and 4 of oxygen.

7. Combination by Weight.—One cubic foot of hydrogen combines with just 1 cubic foot of chlorine. But upon weighing each gas it is found that the cubic foot of chlorine weighs 35.5 times as much as the cubic foot of hydrogen. A cubic foot of oxygen weighs 16 times as much as a cubic foot of hydrogen.

It has been stated that at a given pressure and temperature equal volumes of gases contain the same number of molecules. Therefore, 1 cubic foot of oxygen must contain the same number of atoms as 1 cubic foot of hydrogen. Now, since the former weighs 16 times as much as the latter, it follows that an atom of oxygen weighs 16 times as much as an atom of hydrogen. Similarly, an atom of chlorine weighs 35.5 times as much as an atom of hydrogen. This ratio between the weight of an atom of any element and the weight of an atom of hydrogen is called the **atomic weight** of the element. The atomic weight of any element (or compound) may be found by dividing the weight of a given volume, say 1 cubic foot of the element when in a gaseous state, by the weight of 1 cubic foot of hydrogen when both are at the same temperature and pressure. The atomic weight is, therefore, much the same thing as specific gravity, except that the weight of hydrogen is used as the standard of comparison instead of the weight of water.

8. The atomic weights of the elements named above are as follows:

Hydrogen (H)	1
Oxygen (O)	16
Nitrogen (N)	14
Carbon (C)	12
Sulphur (S)	32

By the aid of these atomic weights, the composition of any substance by weight can be found when its symbol is known. Take water, symbol H_2O; that is, there are 2 atoms of H to 1 of O. Multiply the number of atoms of each by the atomic weight of the atom. Thus,

$$\begin{array}{rl} 2 \times 1 = 2 & \text{parts by weight of hydrogen.} \\ 1 \times 16 = 16 & \text{parts by weight of oxygen.} \\ \hline 18 & \text{parts by weight of water.} \end{array}$$

Then the water is composed of $\frac{2}{18} = 11.11$ per cent. of hydrogen and $\frac{16}{18} = 88.89$ per cent. of oxygen.

As another example, take carbon dioxide, CO_2. We have

1 atom of $C \times$ atomic weight, $12 = 12$ parts by weight of C.
2 atoms of $O \times$ atomic weight, $16 = \underline{32}$ parts by weight of O.
44 parts by weight of CO_2.

Hence, CO_2 contains $\frac{12}{44} = 27.27$ per cent. carbon, and $\frac{32}{44} = 72.73$ per cent. oxygen. From these examples, it is plain that the atomic weight of water is 18 and of carbon dioxide 44.

9. Mixtures.—Two or more substances, either elements or compounds, may be mixed together and yet not combined to form a new substance. They are then said to form a **mixture.** The mixture has the properties of the substances composing it. The most familiar example of a mixture is ordinary air. It is composed of oxygen and nitrogen, 23 parts by weight of the former to 77 parts by weight of the latter. The two gases are not combined chemically; they are simply mixed.

ELEMENTS OF COMBUSTION.

10. Combustion *is a very rapid chemical combination.* The atoms of some of the elements have a very great affinity or attraction for those of other elements, and when they combine they rush together with such rapidity and force that heat and light are produced. Oxygen, for example, has a great attraction for nearly all the other elements. An atom of oxygen is ready to combine with almost any substance with which it comes into contact. For carbon, oxygen has a particular liking, and whenever these two elements come into contact at a sufficiently high temperature, they combine with great rapidity. The combustion of coal in the furnace of a boiler is of this nature. The temperature of the furnace is raised by kindling the fire, and then the carbon of the coal begins to combine with oxygen taken from the air. The combination is so rapid and violent that a great quantity of heat is given out.

The elements that enter into combustion are oxygen, and, usually, either carbon or hydrogen. Coal, wood, and other fuels are composed almost entirely of these three elements. *Combustion is, therefore, the rapid chemical combination of oxygen with either carbon or hydrogen, or both.*

11. We have seen that when carbon and oxygen combine they form CO_2, or carbon dioxide; when hydrogen and oxygen combine they form water, H_2O. These are called the **products of combustion.** When, as is ordinarily the case, the oxygen is obtained from the air, the nitrogen of the air passes into the furnace with the oxygen. It takes no part in the combustion, but passes through the furnace and up the chimney with the CO_2 without any change in its nature; it is, however, usually called a product of combustion in air.

12. Weight of Air Required for Combustion.—It was shown that CO_2 is composed by weight of 12 parts of carbon and 32 parts of oxygen. Hence, to burn a pound of carbon requires $\frac{32}{12} = 2\frac{2}{3}$ pounds of oxygen. If the oxygen is taken from the air, it will take $2\frac{2}{3} \div .23 = 11.6$ pounds of air to supply the $2\frac{2}{3}$ pounds of oxygen. This is because only 23 per cent. of air is oxygen. The combustion of a pound of carbon may be represented as follows:

	Elements.	Products.
1 pound carbon....	1 pound carbon.....	3.67 pounds CO_2
11.6 pounds air.......	2.67 pounds oxygen ...	
	8.93 pounds nitrogen..	8.93 pounds nitrogen
12.6	12.6	12.6

That is, 1 pound of carbon requires 11.6 pounds of air for complete combustion. Of this air, 2.67 pounds is oxygen, which combines with the pound of carbon, forming 3.67 pounds of carbon dioxide. The 8.93 pounds of nitrogen contained in the air pass off with the CO_2 as a product of combustion.

Take, next, the complete combustion of 1 pound of hydrogen. The product of the combustion is water, H_2O. It has been shown that H_2O is composed by weight of 2 parts hydrogen to 16 parts oxygen. Hence, 1 pound of H requires $\frac{16}{2} = 8$ pounds of O to unite with it. The air required to furnish 8 pounds of O is $8 \div .23 = 34.8$ pounds. The process of combustion is, therefore, as follows:

	Elements.	Products.
1 pound hydrogen..	1 pound hydrogen..	9 pounds water (H_2O)
34.8 pounds air	8 pounds oxygen ...	
	26.8 pounds nitrogen..	26.8 pounds nitrogen
35.8	35.8	35.8

13. There is one other case that may occur; the combustion of carbon may not be complete. If insufficient air or oxygen is supplied to the burning carbon, it is possible for the carbon and oxygen to form another gas, carbon monoxide, or CO, instead of carbon dioxide, CO_2.

The combustion of 1 pound of carbon to form CO, of course, requires only one-half the oxygen that would be necessary to form CO_2. This is because in CO gas 1 atom of carbon seizes 1 atom of oxygen instead of 2. To burn 1 pound of carbon to CO_2 requires 11.6 pounds of air. To burn it to CO would, therefore, require but 5.8 pounds of air.

14. The quantities of air required for combustion are shown in the following scheme:

1 Pound.	Air at 62°.	Product of Combustion.
Hydrogen.....	34.8 lb., or 457 cu. ft.	Water. Nitrogen.
Carbon burned to CO_2......	11.6 lb., or 152 cu. ft.	Carbon dioxide. Nitrogen.
Carbon burned to CO	5.8 lb., or 76 cu. ft.	Carbon monoxide. Nitrogen.

15. The fuels in common use are composed chiefly of carbon with sometimes a small percentage of hydrogen, oxygen, and incombustible matter, called *ash*. When the percentages of carbon and hydrogen are known, the air required for the combustion of 1 pound of the fuel is easily found. For example, suppose a certain coal is 90 per cent.

carbon and 10 per cent. hydrogen. To burn the carbon requires $152 \times \frac{90}{100} = 136.8$ cubic feet of air; to burn the hydrogen requires $457 \times \frac{10}{100} = 45.7$ cubic feet of air. Hence, to burn 1 pound of the fuel requires $136.8 + 45.7 = 182.5$ cubic feet of air.

Rule 1.—*To find the air required to burn a given fuel: To the carbon contained in the fuel add 3 times the hydrogen, multiply the sum by 1.52, and the result will be the air required, in cubic feet, at a temperature of 62° F.*

Let A be the number of cubic feet of air required for the combustion of a given fuel; let C be the percentage of carbon and H the percentage of hydrogen, both being expressed as so many parts in 100.

Then,
$$A = 152 \times \frac{C}{100} + 457 \times \frac{H}{100},$$
or
$$A = 1.52\,(C + 3\,H), \text{ nearly.}$$

EXAMPLE.—The composition of a certain kind of coal is as follows:

Carbon	84 parts.
Hydrogen	5 parts.
Oxygen	7 parts.
Ash	4 parts.
	100

Find the quantity of air required to completely burn 1 pound of this fuel.

SOLUTION.—According to rule **1**,

$$A = 1.52\,(84 + 3 \times 5) = 150.48 \text{ cu. ft.} \quad \text{Ans.}$$

When the fuel already contains oxygen, a little less air is required to burn it; if it contains sulphur, a little more air will be required than given by the above rule. In either case the difference is very slight. It will be found that 1 pound of coal requires practically the same amount of air, whether it be anthracite or bituminous. Roughly speaking, it requires about 12 pounds, or 160 cubic feet, of air to burn 1 pound of carbon or coal. If less air is supplied, the combustion is imperfect; that is, the carbon burns to CO instead of CO_2.

16. Heat of Combustion.—The quantities of heat produced by the complete combustion of the elements composing the fuels have been found by experiment. They are as follows:

Hydrogen	62,000 B. T. U. per pound.
Carbon burned to CO_2.	14,600 B. T. U. per pound.
Carbon burned to CO .	4,400 B. T. U. per pound.

Rule 2.—*To find the heat of combustion of 1 pound of fuel, multiply the percentage of carbon by 146 and the percentage of hydrogen by 620. Add the products and the sum will be the required heat of combustion in B. T. U.*

Let B represent the B. T. U. produced by the combustion of a fuel; let C and H represent, respectively, the percentages of carbon and hydrogen composing the fuel expressed as parts in 100.

Then, $$B = 14{,}600 \times \frac{C}{100} + 62{,}000 \times \frac{H}{100},$$
or $$B = 146\,C + 620\,H.$$

Example.—A variety of coal has the following composition:

Carbon	76.5 parts.
Hydrogen	4.4 parts.
Oxygen	3.0 parts.
Nitrogen	1.1 parts.
Ash	15.0 parts.
	100.0

How many B. T. U. will be produced by the combustion of 1 pound of this coal?

Solution.—According to rule 2,

$$B = 146 \times 76.5 + 620 \times 4.4 = 13{,}897 \text{ B. T. U.} \quad \text{Ans.}$$

From the Steam Table it is found that to change 1 pound of water at 212° into steam at 212° requires 966+ B. T. U.; hence:

Rule 3.—*To find the number of pounds of water at 212° evaporated by 1 pound of fuel, divide the heat of combustion of the fuel by 966*

EXAMPLE.—How many pounds of water at 212° can be evaporated by 1 pound of the coal of the last example?

SOLUTION.—The heat of combustion is 13,897 B. T. U.

$$13,897 \div 966 = 14.38 \text{ lb. Ans.}$$

17. Temperature of Combustion.—The theoretical temperature of the combustion of a given fuel can be easily calculated. Making no allowance for losses of heat and supposing that just enough air is furnished for the combustion, burning carbon should have a temperature about 4,940° above zero; burning hydrogen should have a temperature of about 5,800° above zero. In practice, these temperatures are never attained on account of the losses of heat. Usually, the quantity of air admitted to the furnace is from 50 to 100 per cent. more than is theoretically necessary for the combustion. This extra quantity of air enters at a temperature of 60° or 70°, and escapes up the chimney at a temperature of from 400° to 600°. A large quantity of heat is thus wasted and the temperature of the fire is greatly lowered. Where the fire is outside the boiler and the furnace is surrounded by brickwork, the furnace temperature may be 2,500° or 3,000°; but when the furnace is inside the boiler and is surrounded on all sides by water, the temperature rarely rises above 2,000° and is usually less. A high temperature is desirable, since the water of the boiler will take up heat much faster at high temperatures than at low temperatures; combustion is also more perfect at high temperatures.

EXAMPLES FOR PRACTICE.

1. How many pounds of air will be required for the perfect combustion of 7 pounds of carbon? Ans. 81.2 lb.

2. A fuel is 88 per cent. carbon and 12 per cent. hydrogen. How many cubic feet of air are required for complete combustion of 1 pound of the fuel? Ans. 188.48 cu. ft.

3. (*a*) How many B. T. U. would the combustion of the pound of fuel of example 2 give out? (*b*) How many pounds of water at 212° would 1 pound of this fuel evaporate?

Ans. $\begin{cases} (a) & 20,288 \text{ B. T. U.} \\ (b) & 21 \text{ lb.} \end{cases}$

4. The chemical symbol of the product of combustion of sulphur with oxygen is SO_2 (sulphurous oxide). What is the composition of this gas by weight?

Ans. { Sulphur 50%.
Oxygen 50%.

5. Assume that, with ordinary draft, double the theoretical quantity of air is used to burn a fuel. Under these circumstances, how many cubic feet of air would be required to burn 115 pounds of coal, the chemical composition being *H*. 5 parts; *C*. 90 parts; *O*. 3 parts; and ash, 2 parts; total, 100 parts. Ans. 36,708 cu. ft.

FUELS.

FUELS USED IN STEAM MAKING.

18. Introduction.—The fuels used in the generation of steam are chiefly coal, coke, wood, the mineral oils (such as petroleum), and natural gas. Other fuels, such as the waste gases from blast furnaces, straw, bagasse (refuse from sugar cane), dried tan bark, green slabs, sawdust, peat, etc. are also used. All these fuels are composed either of carbon alone or carbon in combination with hydrogen, oxygen, and non-combustible substances.

CLASSIFICATION OF COAL.

19. Leading Varieties.—A prominent authority, Mr. William Kent, divides coal into four leading varieties, as follows:

1. *Anthracite coal*, which contains from 92.31 to 100 per cent. of fixed carbon and from 0 to 7.69 per cent. of volatile hydrocarbons.

2. *Semi-anthracite coal*, which contains from 87.5 to 92.31 per cent. of fixed carbon and from 7.69 to 12.5 per cent. of volatile hydrocarbons.

3. *Semi-bituminous coal*, which contains from 75 to 87.5 per cent. of fixed carbon and from 12.5 to 25 per cent. of volatile hydrocarbons.

4. *Bituminous coal*, which contains from 0 to 75 per cent. of fixed carbon and from 25 to 100 per cent. of volatile hydrocarbons.

20. Anthracite coal is rather hard to ignite and requires a strong draft to burn it. It is quite hard and shiny; in color it is a grayish black. It burns with almost no smoke; this fact gives it a peculiar value in places where smoke is objectionable.

21. Anthracite coal is known to the trade by different names, according to the size into which the lumps are broken. These names, with the generally accepted dimensions of the screens over and through which the lumps of coal will pass, are given in the following table:

Culm passes through 3/16-inch round mesh.

Rice passes over 3/16-inch mesh and through ⅜-inch square mesh.

Buckwheat passes over ⅜-inch mesh and through ½-inch square mesh.

Pea passes over ½-inch mesh and through ¾-inch square mesh.

Chestnut passes over ¾-inch mesh and through 1⅝-inch square mesh.

Stove passes over 1⅝-inch mesh and through 2-inch square mesh.

Egg passes over 2-inch mesh and through 2¾-inch square mesh.

Broken passes over 2¾-inch mesh and through 3½-inch square mesh.

Steamboat passes over 3½-inch mesh and out of screen.

Lump passes over bars set from 3½ to 5 inches apart.

22. Semi-anthracite coal kindles easily and burns more freely than the true anthracite coal. Hence, it is highly esteemed as a fuel. It crumbles readily and may be distinguished from anthracite coal by the fact that when just fractured it will soil the hand, while anthracite will not do so. It burns with very little smoke. Semi-anthracite coal is broken into different sizes for the market; these sizes are the same and are known by the same trade names as the corresponding sizes of anthracite coal.

23. Semi-bituminous coal differs from semi-anthracite coal only in having a smaller percentage of fixed carbon and more volatile hydrocarbons. Its physical properties are practically the same, and since it burns without the smoke and soot emitted by bituminous coal, it is a valuable steam fuel.

24. Bituminous coal may be broadly divided into three general classes:

1. *Caking Coal.*—This name is given to coals that, when burned in the furnace, swell and fuse together, forming a spongy mass that may cover the whole surface of the grate. These coals are difficult to burn, since the fusing prevents the air passing freely through the bed of burning fuel; when caking coals are burned, the spongy mass must be frequently broken up with the slice bar, in order to admit the air needed for its combustion.

2. *Free Burning Coal.*—This is often called non-caking coal from the fact that it has no tendency to fuse together when burned in a furnace.

3. *Cannel Coal.*—This is a grade of bituminous coal that is very rich in hydrocarbons. The large percentage of volatile matter makes it valuable for gas making, but it is little used for the generation of steam, except near the places where it is mined.

25. Bituminous and semi-bituminous coals are known to the trade by the following names:

Lump coal, which includes all coal passing over screen bars 1¼ inches apart.

Nut coal, which passes over bars ¾ inch apart and through bars 1¼ inches apart.

Pea coal, which passes over bars ⅜ inch apart and through bars ¾ inch apart.

Slack, which includes all coal passing through bars ⅜ inch apart.

26. Lignite, according to the classification, comes under the general head of bituminous coal. Properly speaking, it occupies a position between peat and bituminous coal, being probably of a later origin than the latter. It has an uneven fracture and a dull luster. Its value as a steam fuel is limited, since it will easily break in transportation. Exposure to the weather causes it to absorb moisture rapidly; it will then crumble quite readily. It is non-caking and yields but a moderate heat, and is in this respect inferior to even the poorer grades of bituminous coal.

27. Coke is made from bituminous coal by driving off its volatile constituents. It is used chiefly for metallurgical purposes, though it is a valuable fuel for steam purposes.

28. Wood is much used in localities where it is abundant. The effective heating value of different kinds of wood differs but very little.

29. Bagasse is the refuse left after the juice has been extracted from the sugar cane by means of the mill rolls. It is used to some extent in tropical and semitropical countries. Naturally, its use is limited to the places where the sugar cane is grown.

Dried tan bark, straw, slabs, and sawdust being refuse, their use is local and usually confined to tanneries, planing and sawmills, and threshing outfits.

30. Petroleum is occasionally used as a fuel and, as such, possesses some advantages, among which are the ease of lighting and controlling the fire, the uniformity of combustion, and the economy in labor. Its disadvantages are: danger of explosion, loss of fuel by evaporation, and high price in comparison with coal. The Standard Oil Company stimate that 173 gallons of petroleum is equal to 1 long on (2,240 pounds) of coal, allowing for all savings incidenal to its use.

31. Natural gas is abundant in parts of Ohio and Pennsylvania, and is there often used as a fuel for the generation of steam. On an average, 30,000 cubic feet of natural gas is the equivalent of 1 ton of coal.

32. Waste gases from the furnaces of rolling mills and from blast furnaces are extensively used. Naturally, their use is limited to the places where they are produced.

33. Peat may be classified as occupying an intermediate position between wood and coal. When first cut, it is totally unfit for fuel, since it contains from 75 to 80 per cent. of water. When dried, it makes a fairly good fuel.

The Babcock and Wilcox Company state that on the average 1 pound of good bituminous coal may be considered as the equivalent of 2 pounds of dry peat, 2½ pounds of dry wood, 2½ to 3 pounds of dry tan bark or sun-dried bagasse, 3 pounds of cotton stalks, 3¾ pounds of straw, 6 pounds of wet bagasse, and from 6 to 8 pounds of wet tan bark.

FIRING.

SYSTEMS OF HAND FIRING.

34. The style of **firing** to be adopted in any given case depends largely on the conditions present, such as the kind of fuel used, the intensity of the draft, the demand for steam, etc.

There are three methods of hand firing, known as *coking* firing, *spreading* firing, and *alternate* firing, in common use. Each of these methods has advantages peculiar to itself, and none is applicable to all cases and all conditions, that is, if economy in the generation of steam is an object.

35. The **coking system** of firing is especially adapted to bituminous coals which are rich in volatile matter. The coal is first piled on the dead plate near the door and there allowed to coke. After coking from 20 to 30 minutes the hydrocarbons will have been driven off. The coke is then pushed toward the bridge and distributed evenly over the fire. A new charge of coal is immediately heaped upon the dead plate.

This is one of the most economical methods of burning bituminous coal; if properly managed it will give excellent results in regard to the prevention of smoke. In order to get good results, the furnace door should be perforated and a suitable damper fitted for opening and closing the perforations. The air admitted in jets through the openings mixes intimately with the gases formed; the mixture passes to the rear over the bed of burning coke on the grate, where the temperature is high enough to secure their ignition and complete the combustion before they are chilled by contact with the cold surfaces of the boiler and tubes.

36. To secure success with this method, the coal should be charged in small quantities and allowed to remain on the dead plate until it is as thoroughly coked as possible; 30 minutes will, in general, be sufficient. As a matter of course, actual trial in each and every case will have to determine the proper length of time. Large lumps that will coke slowly must be broken up; if the coal cakes badly in coking, the crust thus formed must be broken with the slice bar from time to time, so as to secure the complete removal of the hydrocarbons. The size of the grate and the intensity of the draft should be such that the coke will be burned at as high a rate of combustion, per square foot of grate surface, as the conditions will permit. This results in a high furnace temperature that promotes complete combustion of the gases.

Coking firing for stationary work is but little practiced in the United States, but is much used in marine work in all parts of the world and for stationary work in European countries. It is best adapted for cases where the demand for steam is moderately regular, since with coking firing it is somewhat difficult to force the boiler when there is a sudden heavy demand for steam. Coking firing should never be adopted for anthracite coal.

37. The **spreading system** of firing consists of covering the whole of the grate evenly with the fresh charge of coal. It is the system in most common use. While good results can be obtained by it, if the firing is done by a skilled fireman, it is not particularly to be recommended either for economical or for smokeless combustion. Best results will be obtained from the spreading system by firing light charges at frequent intervals. The habit that many unskilled firemen have of covering the incandescent coke on the grate with a thick layer of fresh coal naturally results in a lowering of the furnace temperature far below the ignition point of the hydrocarbons driven off. In consequence, there is an enormous waste of heat, and, with bituminous coal, vast quantities of black smoke are produced. To prevent this heat loss, the firing *must* be light and frequent. The spreading system is best adapted to anthracite coal in sizes larger than pea coal.

38. In the **alternate system** of firing, the coal is thrown alternately on each side of the furnace; at one firing one side of the grate is spread with coal, and at the next firing the other side receives the charge. This method is preferable to the spreading system in that the whole of the furnace is not cooled off at once by the fresh fuel. While it keeps a bright bed of fuel in at least one side of the furnace and tends to keep the average temperature of the furnace nearly constant, it cannot be recommended as being the best method for securing complete combustion of the hydrocarbons that form a valuable constituent of bituminous coal. The gases from the freshly fired coal, instead of being passed over the bright bed of fuel on the other side of the furnace, are likely to pass directly to the chimney without being sufficiently heated to secure their ignition and complete combustion.

For both bituminous and anthracite coals, it is preferable to the spreading system, however, since gas explosions in the furnace are not as likely to occur as when the spreading system is used.

39. Gas Explosions.—Explosions of the gases in the furnace, commonly called **back draft,** occur usually with small coal and are the result of careless firing. When the smaller sizes of anthracite or bituminous coal are burned with the spreading system, and when a heavy charge is put into the furnace, it is entirely feasible to obtain an explosive mixture of air and gas needing but a spark to ignite it. Owing to the interstices between the pieces of coal being small and tortuous with the smaller coals, the hydrocarbons driven off from the heavy charge are not ignited as rapidly as formed and, hence, collect and mix with the air above the grate, forming an explosive mixture if the conditions are right. All danger of a gas explosion is obviated if the firing is done very lightly, or if the alternate system is adopted, or if some part of the fire is left uncovered when putting in fresh coal, thus igniting the hydrocarbons as quickly as they are distilled off. The smaller the size of the coal, the greater is the liability of a gas explosion with a heavy charge fired spreading. With coals of sizes larger than pea coal, there is little danger of an explosion when fired spreading, except when fired thick instead of light.

DRAFT.

METHODS OF PRODUCING DRAFT.

40. The air required by the furnace for the combustion of the fuel is supplied by the draft. There are two ways of making a draft:

1. By means of a chimney.
2. By means of a fan or blower.

NATURAL DRAFT.

41. Natural draft is produced by the difference between he weight of a column of hot gases contained within a chimney and the weight of the same bulk of cold air. It is well known that any gas, when heated, is lighter, bulk for bulk, than when cool. Now, when the hot gases pass into the chimney they have a temperature of 400° or 500°, while the air outside the chimney has a temperature of from 40° to 90°. Roughly speaking, the air weighs twice as much, bulk for bulk, as the hot gases. Naturally, then, the pressure in the chimney is a little less than the pressure of the outside air. Consequently, the air will flow from the place of higher pressure to the place of lower pressure; that is, into the chimney through the furnace.

42. As an example, suppose that a chimney is 150 feet high and that the temperature of the hot gases is 500°. A column of gas at this temperature, 150 feet high, and of 1 square foot cross-section, weighs about $6\frac{1}{2}$ pounds. A column of air at 60°, of the same length and cross-section, weighs about $11\frac{1}{2}$ pounds. Hence, the difference in pressure at the bottom of the chimney is $11\frac{1}{2} - 6\frac{1}{2} = 5$ pounds per square foot. In other words, the pressure of the draft is 5 pounds per square foot.

It is customary to express the pressure of the draft in inches of water. It has been shown that the pressure of the atmosphere, 14.7 pounds per square inch, supports a column of water 34 feet high.

$$34 \text{ ft. of water} = 14.7 \text{ lb. per sq. in.};$$

$$\text{or,} \quad 34 \times 12 = 408 \text{ in. of water} = 14.7 \text{ lb. per sq. in.};$$

$$= 2{,}116.8 \text{ lb. per sq. ft.}$$

$$\text{Therefore, 1 inch of water} = \frac{14.7}{408} = .036 \text{ lb. per sq. in.};$$

$$= \frac{2{,}116.8}{408} = 5.2 \text{ lb. per sq. ft.}$$

43. The intensity of the draft is measured by means of a water gauge shown in Fig. 1. As will be seen, it is a glass tube open at both ends, bent to the shape of the letter **U**; the left leg communicates with the chimney. The air outside the chimney being heavier, it presses on the surface of the water in the right leg and forces some of it up the left leg; the difference in the two water levels *H* and *Z* in the legs represents the intensity of the draft and is expressed in inches of water.

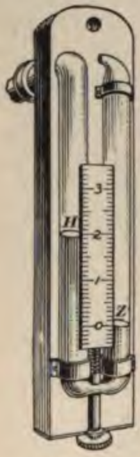

FIG. 1.

44. The draft pressure required depends on the kind of fuel used. Wood requires but little draft, say ½ inch or less; bituminous coal generally requires less draft than anthracite. To burn anthracite, slack, or culm, the draft pressure should be 1¼ inches of water.

The chimney is used both to create a draft and to carry off the obnoxious products of combustion. The draft produced by a chimney may vary from ¼ inch to 2 inches of water, depending on the temperature of the chimney gases and on the height of the chimney. Generally speaking, it is advantageous to use a high chimney and as low a temperature as possible for the gases.

MECHANICAL DRAFT.

45. Artificial draft is produced by means of fan blowers or steam jets. According to the manner in which it is applied, it is known as *forced draft* or *induced draft*. In a forced-draft installation, the air is forced into the ash-pit by suitable means; in an induced-draft installation, a partial vacuum is created in the chimney. Both of these systems are in common use.

46. Forced Draft.—For forcing air under pressure into the ash-pit, either a fan blower or steam jet may be used. A common construction of a fan blower is shown in Figs. 2 and 3. The shell, or housing, is made of steel plate, with a substantial base of cast iron or wrought iron. An outlet is placed at the desired point of the circumference, whence the air is discharged into the duct leading to the ash-pit. In the fan shown in Fig. 2 there is one inlet, which has the fan shaft in its center and is on the side farthest from the pulley and support. The fan shaft is supported in two bearings and carries the fan wheel within the casing. The usual construction of the fan wheel is shown in Fig. 3. Arms made of T iron are fastened to the hubs and carry at their ends the blades. These blades are tied together by the side plates.

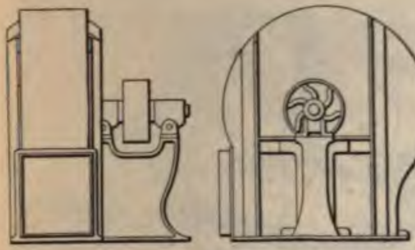

FIG. 2.

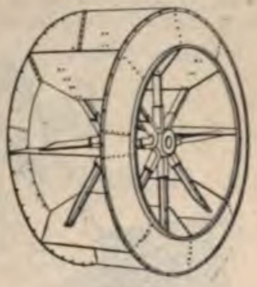

FIG. 3.

The fan is operated by a belt from an engine or may have an engine connected directly to it. The air discharged by the fan may be introduced into the ash-pit through an opening in the bottom of the bridge wall, which is then built hollow, as shown in Fig. 4. The opening is closed by the

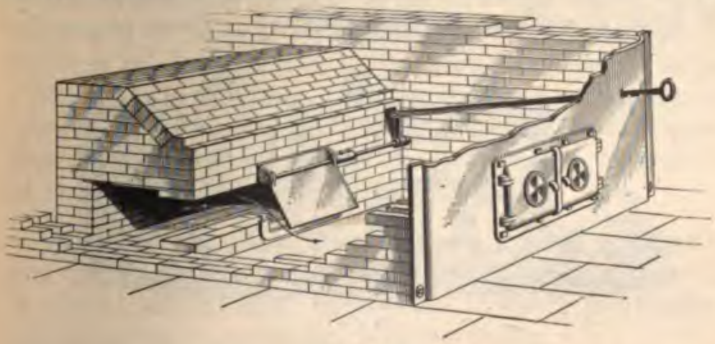

FIG. 4.

damper shown. This arrangement is recommended for a new boiler plant. When the fan draft is applied to an old plant, the air may be introduced in front through an opening in the bottom of the ash-pit, as shown in Fig. 5. When the damper is closed, the ashes may be readily raked over it. The damper when opened serves to thoroughly distribute the air in the ash-pit. The ducts leading to the ash-pit may be underground, as shown in Fig. 6. There is one duct along the front of the boilers, with one branch for each ash-pit. When a low first cost is essential, galvanized-iron pipes may be used for ducts, with the main pipe overhead and a branch pipe extending down to each boiler. While the

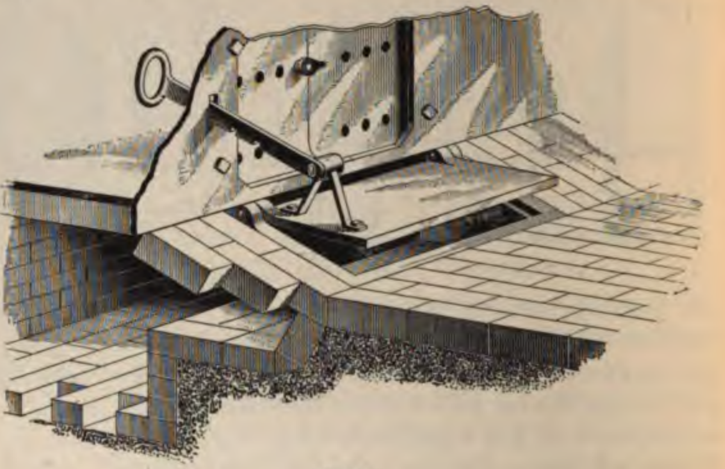

FIG. 5.

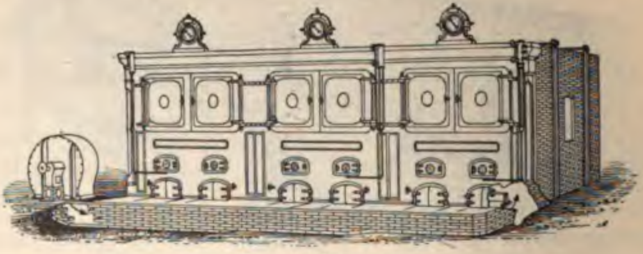

FIG. 6.

nstallation of a fan blower is more costly than that of a team jet, it is much more economical in running than the atter.

47. A **McClave argand steam blower** for forcing air into the ash-pit is shown in Fig. 7. The blower consists of a long air tube *t* discharging from the end *s* below the grate. In the other end of the tube is placed a ring-shaped tube *r*, perforated on the right with small holes. Steam from the boiler is led into the ring by the pipe *l* and escapes in jets through the perforations, carrying air along with it into the ash-pit. This method of producing a forced draft is extensively used in the coal regions for burning the finer grades of anthracite coal and for bituminous slack.

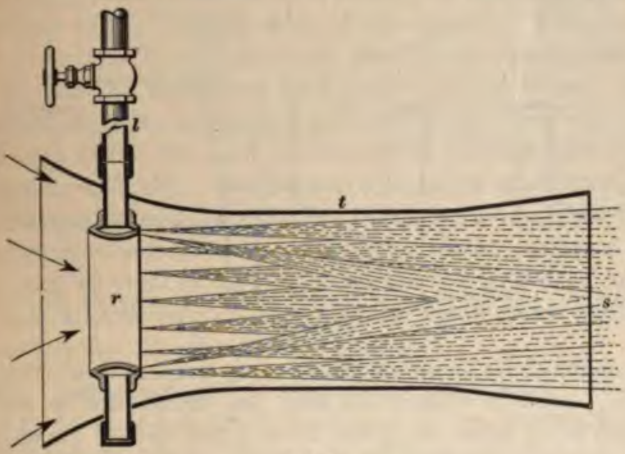

FIG. 7.

48. **Induced draft,** or **suction draft,** as it is occasionally called, may be produced by a fan placed in the uptake. A typical induced-draft installation, in which the engine is connected direct to the fan, is shown in Fig. 8.

The fan, when running, creates a partial vacuum in the uptake and furnace, thereby causing the outside air, under the influence of its greater pressure, to flow into the ash-pit. The fan may be placed directly over the boilers, as shown in

Fig. 8, and discharge the gases into a short steel stack; or, it may be placed where most convenient. When applying induced-fan draft to an old plant using natural draft, the fan may be placed in connection with the smoke flue in such a manner as to draw the gases from it and return them to it again at a point farther on, whence they pass to the existing chimney. Suitable dampers serve to switch off the fan and pass the gases directly through the flue when the fan is not in service.

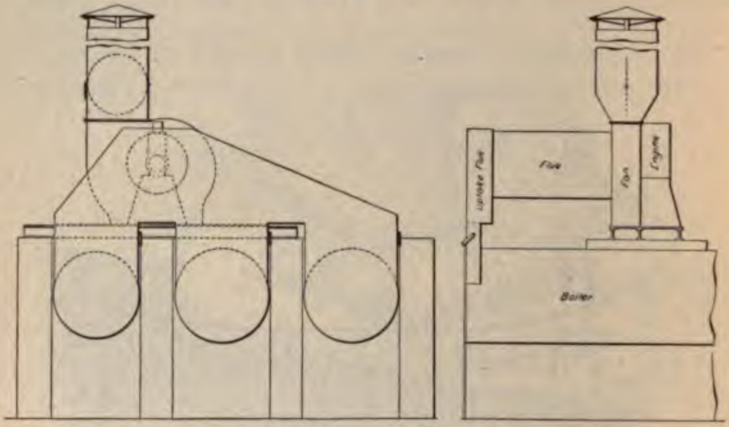

FIG. 8.

A vacuum may also be caused in the chimney by means of a steam jet; this is a method commonly adopted in locomotives, in which the exhaust nozzle is placed in the stack, and the exhaust steam, by carrying with it the air in the stack, creates the draft. This method is seldom used in stationary practice.

ADVANTAGES OF MECHANICAL DRAFT.

49. Mechanical draft possesses certain advantages over natural draft which in many cases make it advisable to substitute it for natural draft. These advantages are as follows:

50. Adaptability.—Blowers may be applied under almost all circumstances and are independent of location.

They may be used to assist an existing chimney in order to help a plant weak in chimney power or primarily for the creation of draft.

51. Ease of Control and Flexibility.—A fan may be automatically controlled to produce a very close approach to a uniform steam pressure by attaching an automatic damper regulator to the throttle valve of the engine. With natural draft, the intensity of the draft depends on the intensity of the fire, and is, therefore, least when the fire is low. With mechanical draft, however, the draft is independent of the condition of the fire, and, consequently, banked fires may be started up quickly. Furthermore, it can be readily adjusted for the combustion of different kinds of fuel and for widely varying combustion rates. Owing to the intensity of draft that may be created, not only can the low grades of coal be burned successfully, but, also, the amount of steam generated by each boiler may be greatly increased.

52. Independence of Climatic Conditions.—As is well known, there is a decided difference in the intensity of the draft produced by a chimney in summer and that produced in winter time. Likewise, on damp and muggy days, the draft is lessened. But mechanical draft is entirely independent of these conditions.

53. Forced draft produced by a steam blower possesses the advantage of cheapness in first cost when applied to a few boilers. For a large installation its cost will probably exceed that of a fan-draft installation, since one steam blower will be required for each ash-pit. Furthermore, the steam consumption of the steam blower is quite high. It seems to be an advantage when used with coals that clinker badly, some engineers reporting that it greatly lessens the trouble from clinkers adhering to the firebrick lining of the furnace.

The draft produced by a steam blower is as flexible and as easily adapted as fan draft. It is, however, difficult to regulate it automatically so as to get satisfactory results.

A SERIES

OF

QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS TREATED OF IN THIS VOLUME.

It will be noticed that the Examination Questions that follow have been divided into sections, which have been given the same numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until that portion of the text having the same section number as the section in which the questions or examples occur has been carefully studied.

ELEMENTS OF ELECTRICITY AND MAGNETISM.

EXAMINATION QUESTIONS.

(1) Fig. I represents a helix of wire around which an electric current is supposed to be circulating in the direction indicated by the arrows. Which of the two ends, *a* or *b*, is the north pole of the solenoid? Why?

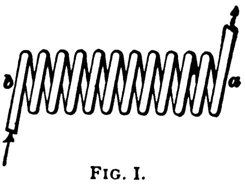

FIG. I.

(2) What will be the sign of the static charge developed (*a*) on a glass rod when rubbed with fur? (*b*) on a piece of sealing-wax when rubbed with silk?

(3) The separate resistances of two branches *A* and *B* of a derived, or shunt, circuit are 16.2 and 14.1 ohms, respectively. If the sum of the currents in the two branches is 6.37 amperes, what is the current in each branch?

Ans. $\begin{cases} \text{2.9643 amperes in branch } A. \\ \text{3.4057 amperes in branch } B. \end{cases}$

(4) In a closed circuit, the resistance between two points is 2.3 ohms. (*a*) What current flowing between these points will cause a difference of potential of 58.4 volts?

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(*b*) What is the power in watts dissipated between these two points? (*c*) Give its equivalent in horsepower.

Ans. (*a*) 25.3913 amperes.
(*b*) 1,482.8521 watts.
(*c*) 1.9877 horsepower.

(5) Fig. II represents a closed circuit consisting of a voltaic battery *B* and two conductors *X* and *Y* connected in series. The internal resistance of the battery is 17.2 ohms, and the separate resistances of the conductors *X* and *Y* are, respectively, 8.2 and 11.3 ohms. What is the total E. M. F. in volts generated by the battery if a current of .75 ampere flows through the circuit? Find the difference of potential in volts between *a* and *b*, between *b* and *c*, and between *c* and *a*.

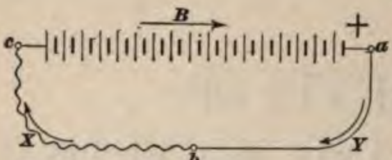

FIG. II.

Ans. Total E. M. F. developed by battery = 27.525 volts.
Difference of potential between *a* and *b* = 8.475 volts.
Difference of potential between *b* and *c* = 6.15 volts.
Difference of potential between *c* and *a* = 14.625 volts.

(6) A voltaic battery whose internal resistance is 36.2 ohms is connected to a copper wire having a resistance of 21.7 ohms. What is the total electromotive force in volts generated in the battery if a current of .127 ampere flows through the circuit? Ans. 7.3533 volts.

(7) How many coulombs of electricity pass through a circuit in 2¼ hours when the strength of current is 8.32 amperes? Ans. 67,392 coulombs.

(8) Given, electromotive force = 112.5 volts and strength of current = 12.2 amperes; find the power in watts.

Ans. 1,372.5 watts.

(9) The resistance of a copper wire is 43.2 ohms at 60° F.; find its resistance at 85° F. Ans. 45.5274 ohms.

(10) The separate resistances of three conductors A, B, nd C are, respectively, 37, 45, and 72 ohms. What is their int resistance when connected in parallel?

Ans. 15.8383 ohms.

(11) The separate resistances of four conductors A, B, C, nd D are, respectively, 3, 19, 72, and 111 ohms; find their oint resistance when connected in series. Ans. 205 ohms.

(12) How much energy in *joules* is expended in a closed circuit during 1¼ hours in which the current is maintained at 14.2 amperes, the resistance of the circuit being 8 ohms?

Ans. 7,259,040 joules.

(13) In Fig. III, the difference of potential between a and b is 11.6 volts. If the strength of the current in branch A is 6.7 amperes and the strength of the current in B is 4.9 amperes, what is the separate resistance of each branch?

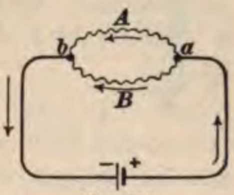

FIG. III.

Ans. $\begin{cases} \text{The separate resistance of branch } A = 1.7313 \text{ ohms.} \\ \text{The separate resistance of branch } B = 2.3673 \text{ ohms.} \end{cases}$

(14) The E. M. F. of a battery is 22.4 volts and its internal resistance is 13.4 ohms. What is the resistance of an external conductor connected to the battery when the current flowing in the circuit is .43 ampere?

Ans. 38.693 ohms.

(15) What must have been the strength of current in amperes in a closed circuit through which 368,422 coulombs of electricity passed in 4½ hours? Ans. 22.7421 amperes.

(16) Find the work done in foot-pounds when a current of 2.4 amperes flows against a resistance of 45 ohms for 50 minutes. Ans. 573,324.48 foot-pounds.

(17) Given, the electromotive force = 525 volts and strength of current = 12.5 amperes; express the number of horsepower. Ans. 8.7969 horsepower.

(18) (*a*) How many watts are dissipated by a current of 110 amperes flowing against a resistance of 4.2 ohms? (*b*) Give its equivalent in horsepower.

Ans. $\begin{cases} (a) & 50{,}820 \text{ watts.} \\ (b) & 68.1233 \text{ horsepower.} \end{cases}$

(19) If the resistance of 1,000 feet of round copper wire .1 inch in diameter is 1 ohm, find the resistance of 2,000 feet of square copper wire .1 inch on a side. Ans. 1.5708 ohms.

(20) Find the equivalent of 54,200 watts in horsepower.
Ans. 72.6541 horsepower.

(21) The specific resistance of mercury is 37.15 microhms per cubic inch; find the resistance in ohms of a round column of mercury 72.3 inches high and .04 inch in diameter, at 32° F. Ans. 2.1368 ohms.

(22) The total E. M. F. developed within a battery is 45 volts and the internal resistance of the battery is 33 ohms; find the strength of current flowing when the battery is connected in circuit with a resistance of 30 ohms.
Ans. .7143 ampere.

(23) An E. M. F. of 510 volts is consumed in an electric receptive device and a current of 24.3 amperes is flowing in the circuit; calculate the power in watts supplied to the receptive device. Ans. 12,393 watts.

(24) A battery of twenty-four cells is arranged in multiple-series as shown in Fig. IV. There are four groups of six cells each, connected in series, and the four groups are connected in multiple, or parallel, to two main conductors c and c'. If the E. M. F. developed by each cell is 1.5 volts, what will be the E. M. F. indicated by the voltmeter *V M* when its binding posts are connected to the main conductors c and c', as shown in the figure?

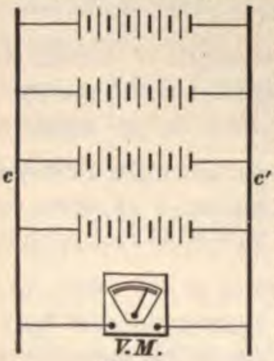

FIG. IV.

(25) The available E. M. F. developed by an electric source is 250 volts and a current of 65.7 amperes is flowing from it; determine its output in horsepower.

Ans. 22.0174 horsepower.

(26) Fig. V represents a horseshoe electromagnet M around which is wound an insulated conductor c c' c''. If a current circulates through the conductor in the direction as indicated by the arrows, which of the two ends, a or b, is the south pole of the magnet?

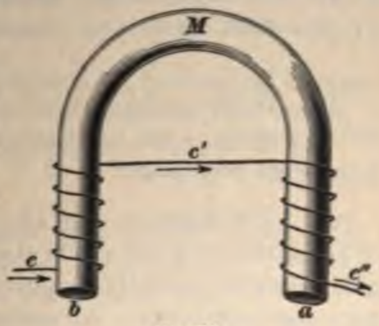

FIG. V.

(27) Give the names of all the known magnetic substances.

(28) A compass C is placed between the north and the south poles of two magnets, as shown in Fig. VI. Toward which pole will the north pole of the compass needle tend to point, and why?

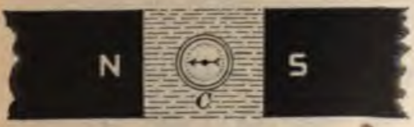

FIG. VI.

(29) A compass C is placed alongside a bar magnet opposite the neutral line, as shown in Fig. VII. Toward which pole of the magnet will the south pole of the compass needle tend to point, and why?

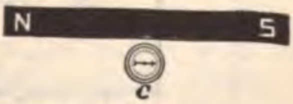

FIG. VII.

(30) In an electromagnet, Fig. VIII, the coil of wire is wound around an iron core in a right-handed spiral. Through which end, a or b, of the wire must the current enter in order to produce the polarity as represented in the figure? Why?

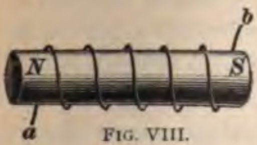

FIG. VIII.

(31) The resistance of a platinum wire 112 feet 6 inches long is 100.8 ohms; calculate the resistance of 11.7 inches of the same wire, other conditions remaining unchanged.
Ans. .8736 ohm.

(32) The resistance of a German-silver wire is 91.8 ohms at 45° F.; calculate its resistance when its temperature is 72° F., other conditions remaining unchanged.
Ans. 92.4048 ohms.

(33) If the resistance of a copper wire is .144 ohm at 87° F., what is its resistance at 41° F., other conditions remaining unchanged? Ans. .131 ohm.

(34) The diagram, Fig. IX, represents a particular pattern of resistance box for a Wheatstone bridge, with battery and galvanometer circuits properly connected for taking resistance measurements. An unknown resistance *X* is connected to the terminals *c* and *b*. After adjusting the resistances of the same by withdrawing the plugs, as represented by the open spaces between the contacts, the galvanometer shows

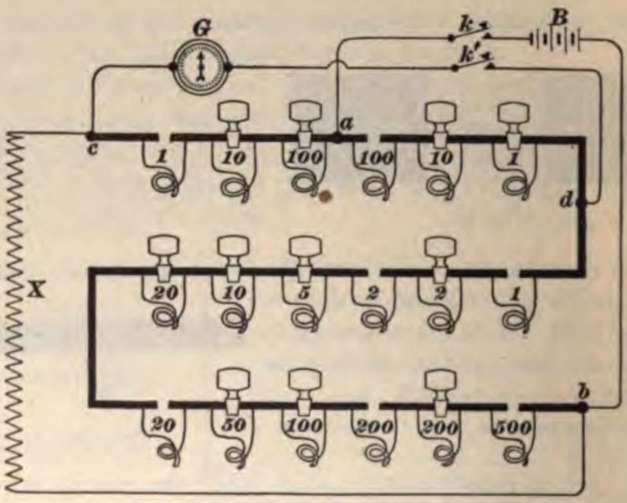

FIG. IX.

no deflection when the keys *k* and *k'* are pressed and the battery and galvanometer circuits are closed. Under these conditions, what is the resistance of *X*? Ans. 7.23 ohms.

(35) The total E. M. F. developed in a closed circuit is 36 volts, the internal resistance is 18 ohms, and the external resistance is 24 ohms; determine the strength of current in amperes flowing in the circuit. Ans. .8571 ampere.

(36) A current of 2.7 amperes is flowing in a closed circuit. If the total E. M. F. developed in the circuit is 12.6 volts, what is the total resistance of the circuit?

Ans. 4.6667 ohms.

(37) The external resistance of a closed circuit is 31.5 ohms and the internal is 11 ohms. If a current of .8 ampere is flowing through the circuit, what is the total E. M. F. in volts developed? Ans. 34 volts.

(38) The total E. M. F. developed in an electric source is 250 volts. If 10 per cent. of this E. M. F. is required to transmit a current of 80 amperes to and from a receptive device situated 600 feet from the source, (*a*) what is the total resistance of the two conductors, and (*b*) what is their resistance per foot, considering each to be 600 feet long?

Ans. { (*a*) .3125 ohm.
(*b*) .00026 ohm per foot.

(39) The internal resistance of a battery is 8.1 ohms and the total E. M. F. developed in it is 24 volts. What is the available or external E. M. F. of the battery when the circuit is completed by an external conductor offering a resistance of 15.9 ohms? Ans. 15.9 volts.

(40) The separate resistances of two branches *A* and *B* of a derived circuit are 1.2 and 2.2 ohms, respectively. If the sum of the currents in the two branches is 45 amperes, what is the current in each branch?

Ans. { The current in branch *A* is 29.1176 amperes.
The current in branch *B* is 15.8824 amperes.

(41) (*a*) What is a kilowatt? (*b*) If a machine has a capacity of 150 kilowatts, what is its capacity in horsepower?
Ans. (*b*) 201.072 horsepower.

(42) A 250-volt dynamo has a capacity of 300 kilowatts, what will be its full-load current? Ans. 1,200 amperes.

(43) (*a*) What is a kilowatt-hour? (*b*) If an average of 40 amperes flows in a 110-volt circuit for 9 hours and 30 minutes, what is the amount of work accomplished, expressed in kilowatt-hours? Ans. (*b*) 41.8 kilowatt-hours.

DYNAMOS AND MOTORS.

EXAMINATION QUESTIONS.

(1) Suppose that a ring-core armature of a bipolar dynamo is wound with 200 complete turns of wire that are properly connected to the segments of a commutator for generating a continuous current, and that there are 6,250,000 lines of force passing through the armature from the poles of the field magnets. If the strength of the field remains constant and the armature is rotated at a uniform speed of 1,200 revolutions per minute, what is the total electromotive force in volts generated in the armature?

Ans. 250 volts.

(2) If the resistance of the field coils in a shunt-wound dynamo is 440 ohms, and the difference of potential between the brushes when the external circuit is open is 220 volts, what is the strength of current in the field coils?

Ans. .5 ampere.

(3) What is the distinction between an alternating current and a continuous current?

(4) Fig. I shows a cross-sectional view of a uniform magnetic field taken at right angles to the direction of the lines of force; that is, the dots represent the ends of the lines of force, their direction being downwards, piercing the paper. *C* represents a closed coil of some conducting material, such as copper, that is placed in the magnetic field with its plane

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at right angles to the direction of the lines of force. If the closed coil is suddenly moved from its original position to another position in the field, as to *C'*, as shown by the dotted coil, without changing the relative position of its plane with the direction of the lines of force, state whether or not a momentary current will circulate around the coil when the movement is made, and give the reason.

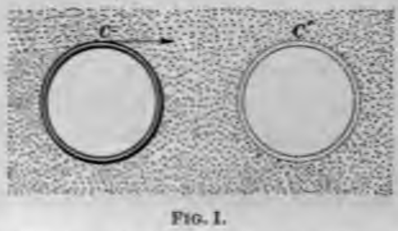

FIG. I.

(5) The output from a certain dynamo is 17,500 watts, and its efficiency at this output is 87.5 per cent. If 2.6 per cent. of the input is used to excite the field magnets, state the field loss in watts. Ans. 520 watts.

(6) The resistance of the shunt field coils of a constant-potential dynamo is 55 ohms and the difference of potential between the brushes when the armature is revolving at normal speed is 110 volts. How many watts are required to excite the field magnets? Ans. 220 watts.

(7) What is a commutator and for what is it used?

(8) The output of a dynamo is 65,000 watts and its efficiency at this output is 90.5 per cent.; determine the input to the armature and express the same in horsepower.

Ans. 96.28 horsepower.

(9) Fig. II shows the connections of a shunt-wound dynamo and the direction in which the field coils are wound. If the current flows in the direction indicated by the arrowheads, which of the two pole pieces, *P* or *P'*, is the north pole? Suppose that the winding of the right-hand coil were reversed, which pole piece would then be the north pole?

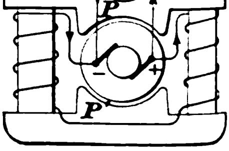

FIG. II.

(10) The input to a dynamo is 10 horsepower and its output is 6,341 watts. What is its efficiency at this load?

Ans. 85 per cent.

(11) Fig. III represents a cross-sectional view of a uniform magnetic field. The dots represent an end view of the lines of force, their direction being downwards, piercing the paper; or, in other words, the observer is looking along the lines of force toward the face of a south pole; *c* represents a moving conductor placed in the magnetic field with its length at right angles to the direction of the lines of force; its two ends are connected to an external circuit consisting of the resistance *R*. If the conductor is moving upwards across the magnetic field in the direction shown by the arrows, in which direction will the current tend to flow in the circuit?

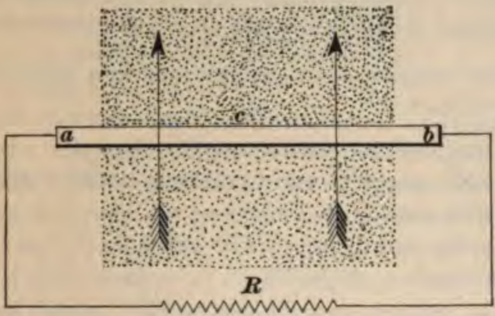

FIG. III.

(12) A dynamo shows an efficiency of 85 per cent. when its output is 11,900 watts, and 1.8 per cent. of the input is lost in the core by eddy currents and hysteresis. What is the core loss in watts?

Ans. 252 watts.

(13) (*a*) What is meant by the *counter torque* of a dynamo? (*b*) What causes it?

(14) A dynamo generates 125 volts at a normal load of 120 amperes; if the resistance of the armature from brush

brush is .040 ohm, what is the armature loss in watts due to resistance? Ans. 576 watts.

(15) In a compound-wound dynamo the resistance of the shunt field coils is 550 ohms and the resistance of the series field coils through which all the current to the external circuit flows is .04 ohm. The dynamo generates 550 volts between its brushes when the output is 40 amperes. Determine the total number of watts lost in the shunt and series field coils combined at this output. Ans. 614 watts.

(16) What causes the neutral points in a dynamo to shift when a current is flowing in the armature conductors?

(17) The separate losses at full load in a particular dynamo are as follows:

Loss in mechanical friction = 356 watts.
Loss in eddy currents and hysteresis = 178 watts.
Loss in field coils = 263 watts.
Loss in armature ($C^2 r$) = 423 watts.
All other losses = 50 watts.

If the output of the dynamo at full load is 15,000 watts, determine its percentage efficiency. Ans. 92.1942 per cent.

(18) In example 17, what percentage of the input is lost (*a*) in mechanical friction? (*b*) in eddy currents and hysteresis? (*c*) in the field coils? (*d*) in the armature wires? (*e*) What is the total percentage of loss in the dynamo?

Ans. {
(*a*) 2.1881 per cent. loss.
(*b*) 1.094 per cent. loss.
(*c*) 1.6165 per cent. loss.
(*d*) 2.5999 per cent. loss.
(*e*) 7.8058 per cent. total loss.

(19) If a certain dynamo generates 440 volts when driven at a speed of 1,200 revolutions per minute, what electromotive force will it generate when driven at 1,400 revolutions per minute, all other conditions in regard to strength of field, armature reactions, and number of armature conductors remaining unchanged? Ans. 513⅓ volts.

(20) What advantage have carbon brushes over copper brushes?

(21) Fig. IV represents a cross-sectional view of a uniform magnetic field. The dots represent an end view of the lines of force, their direction being downwards, piercing the paper; or, in other words, the observer is looking along the lines of force towards the face of a south pole. The ring *C* is a closed coil of some conducting material, as copper, and is placed in the magnetic field with its plane at right angles to the direction of the lines of force. Imagine the coil to be suddenly jerked from its position *C* to one outside the magnetic field, as, for instance, to *C*′, assuming, of course, that its plane is kept always at right angles to the direction of the lines of force. Will a momentary current be produced in the closed coil, and if so, in which direction will it circulate around the ring?

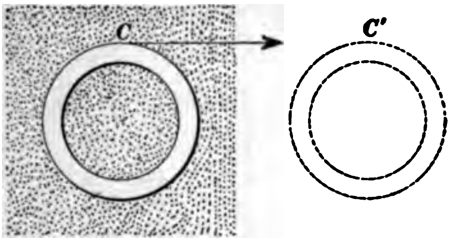

FIG. IV.

(22) What is a compound-wound dynamo, and why are dynamos compound-wound?

(23) If a conductor cuts eight million lines of force in one-quarter of a second, what is the *rate of cutting* per second?

(24) State why a solid piece of iron will not answer for a revolving armature core.

(25) In a particular dynamo, if an electromotive force of 200 volts is generated when there are 750,000 lines of force passing through the armature, what electromotive force would be generated if the strength of the field were increased so that 1,250,000 lines of force passed through the armature, assuming that all other conditions as to speed,

number of conductors, armature reactions, etc., remain unchanged? Ans. 333⅓ volts.

(26) To what are the following losses in a dynamo due: (*a*) core loss? (*b*) armature loss? (*c*) field loss?

(27) In Fig. V, the observer is looking at the face of a north magnetic pole *N* and a straight conductor *C* is placed in a vertical position in front of the pole with its length at right angles to the direction of the lines of force as they pass from the pole. If the two ends of the conductor are connected to the terminals of the battery *B*, and a current flows through the circuit thus formed in the direction indicated by the arrowheads, toward which side, *a* or *b*, of the pole face will the conductor tend to move?

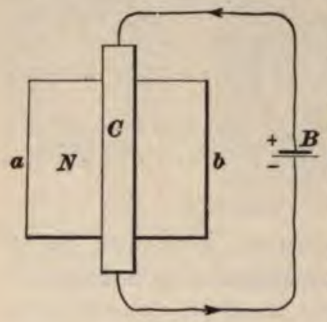

FIG. V.

(28) In a shunt-wound dynamo, if the resistance of the field coil is 650 ohms and the difference of potential between the brushes remains constant at 525 volts when the armature is rotated at a constant speed, what is the strength of current in the field coil under these conditions?

Ans. .8076 ampere.

(29) A compound-wound dynamo generates 115 volts between its terminals when no current is flowing into the external circuit. At full load, however, the difference of potential between its terminals is 124.2 volts. What percentage of over-compounding do these figures represent?

Ans. 8 per cent.

(30) What becomes of the heat generated in a dynamo armature?

(31) State the differences between separately excited, shunt-wound, and series-wound dynamos.

(32) The core losses in a particular generator amount to 800 watts and the input to the generator is 64 horsepower at full load. Determine the percentage of loss in the core at this input. Ans. 1.6756 per cent.

(33) Why must the brushes of the dynamo be shifted ahead of the neutral point when operating under load?

(34) What is the difference between a consequent pole and a salient pole?

OPERATION OF DYNAMOS AND MOTORS.

EXAMINATION QUESTIONS.

(1) Why should the operation of emery wheels, grinders, and speed lathes and the handling of coal not be allowed in the same room with dynamos and engines?

(2) (*a*) On what machines are copper brushes generally used? (*b*) How are copper brushes generally set?

(3) How are (*a*) copper and (*b*) carbon brushes shaped to fit the commutator?

(4) What does the odor of hot oil around a machine usually indicate?

(5) State three possible causes for the refusal of a direct-current shunt motor to start after the main switch has been closed and the starting device properly operated.

(6) To what may the sparking at the brushes of a dynamo be due? Give at least four causes of sparking.

(7) What test may be used to locate defects in an armature?

(8) How would you test the field coils of a dynamo to determine whether any of them were open-circuited or not?

9) should neither ordinary oil, in any considerable uantity, nor emery cloth be used on commutators or ushes ?

(10) Why are carbon brushes used on high-voltage ynamos, especially when they are subject to sudden and iolent changes in the load that cannot be met by shifting the brushes ?

(11) How are (*a*) high and (*b*) low bars in commutators remedied ?

(12) What is the result of continually overloading a dynamo ?

(13) How does a shunt motor act when the shunt field is pened while the motor is running ?

(14) Give three different methods for starting up a rotary transformer.

(15) How does a short-circuited field coil on a shunt dynamo affect the other field coils ?

(16) Describe at least one method for locating a short-circuited armature coil.

(17) In making a bar-to-bar test around an armature, what would be indicated (*a*) by an unusually large deflection of the galvanometer or other testing instrument used ? (*b*) by an unusually small, or no, deflection ?

(18) (*a*) What is the objection to having the pressure between a brush and the commutator too great ? (*b*) What is the objection to having it too small ?

(19) (*a*) What does a narrow scratch or several of them all around a commutator usually indicate ? (*b*) What is the remedy ?

(20) What is the advantage of staggering the brushes on a commutator and having end play for the armature ?

(21) What would a grinding, rumbling noise, accompanied by excessive sparking and, perhaps, some slipping of the belt, indicate in a dynamo or motor ?

(22) What would be the effect of having one field coil reversed in (*a*) a dynamo? (*b*) a motor?

(23) State two reasons why a simple shunt dynamo may refuse to generate when properly rotated at normal speed.

(24) How are synchronous motors generally started?

(25) If only one coil in a motor or dynamo armature, when revolving at normal speed in its own normal field, becomes abnormally hot, what defect is indicated?

(26) What does a broad scratch around the surface of a commutator indicate?

(27) How would you start an induction motor?

HEAT AND STEAM.

EXAMINATION QUESTIONS.

(1) What are the effects of heat on a substance when applied to it?

(2) What do you understand by the temperature of a body?

(3) (*a*) Define the term British thermal unit. (*b*) Give the mechanical equivalent of one unit.

(4) Give an instance of work being changed to heat.

(5) Define (*a*) latent heat of fusion; (*b*) latent heat of steam; (*c*) specific heat.

(6) It requires 1.77 B. T. U. to raise the temperature of 10 pounds of glass from 74° to 75°. What is the specific heat of glass? Ans. .177.

(7) One thousand pounds of steam at 212° is conveyed by pipes through a building; all the steam is condensed and the water of condensation returns to the boiler at a temperature of 192°. If the heat given off is applied to a quantity of water, how many pounds will it raise from 32° to 212°? Ans. 5,477.77 lb.

(8) If we place 10 pounds of water at a temperature of 90°, 15 pounds of mercury at 60°, and 20 pounds of alcohol at 40°, together in a vessel, what will be the temperature of the mixture? Ans. 62.66°.

NOTE.—The specific heat of alcohol is .60.

(9) If a number of substances of different temperatures are mixed together, how does the quantity of heat in the mixture compare with the quantity of heat contained in all the substances before mixing?

(10) If 20 pounds of steam at 212° are mixed with 400 pounds of water at 55°, what will be the temperature of the mixture? Ans. 108.47°

(11) How does change of pressure on the surface of a liquid affect its boiling point?

(12) Define (*a*) saturated steam; (*b*) superheated steam.

(13) Define (*a*) heat of the liquid; (*b*) latent heat; (*c*) total heat; (*d*) specific volume; (*e*) density.

(14) How many B. T. U. are required to change 10 pounds of ice at 25° into steam at 212°? Ans. 12,935.28 B. T. U.

(15) What is the difference between gauge pressures and absolute pressures, and which are given in the Steam Tables?

(16) How many foot-pounds of work will it require to change 40 pounds of water at 90 pounds gauge pressure into steam at the same pressure? Ans. 24,428,172 ft.-lb.

TYPES OF STEAM BOILERS.

EXAMINATION QUESTIONS.

(1) Into what three general classes, according to service, may boilers be divided?

(2) Enumerate the principal parts of a boiler and state the office of each part.

(3) Why are hemispherical heads often used in plain cylindrical boilers?

(4) (*a*) How are plain cylindrical boilers usually supported? (*b*) How are vertical boilers usually supported?

(5) How is the velocity of flow of the gases of combustion regulated?

(6) In setting a boiler, should the fire-line be above or below the water-line, and why?

(7) What is the duty of the (*a*) safety valve? (*b*) steam gauge? (*c*) water gauge?

(8) Where is the blow-off pipe located, and why?

(9) What is the difference in respect to the flow of the gases of combustion between the return-tubular boiler and the plain cylindrical boiler?

(10) In what important respect do the Cornish and Lancashire boilers differ from the return-tubular boilers?

(11) What is the chief objection to internally fired boilers of the Cornish and Lancashire types? Give an important point in their favor.

(12) How is the draft obtained in a locomotive boiler?

(13) What two important makes of water-tube boilers have their tubes set at an angle with the horizontal, and what is the object of having them so arranged?

(14) In the Heine boiler, where is the mud drum located and what is the advantage of having it there?

(15) In the Stirling boiler, how many drums are there and what is the position of the tubes?

(16) Is the Hazelton boiler a fire-tube or water-tube boiler, and how is it supported?

(17) What is the chief point of difference between the Hazelton and the Morrin Climax boiler?

(18) What kind of a boiler would you call the Cahall, and how is the circulation of water arranged for in it?

(19) In the Harrison safety boiler, at what point does the feedwater enter?

(20) Why are water-tube boilers generally safer than fire-tube boilers?

(21) Name some of the advantages and some of the disadvantages of water-tube boilers.

(22) In what ways is the heat transferred from the fuel to the water in a boiler?

(23) State why good water circulation is essential to the satisfactory working of a boiler.

BOILER DETAILS.

EXAMINATION QUESTIONS.

(1) Give two reasons why machine riveting is preferable to hand riveting.

(2) How does the size of the rivet compare with the hole into which it is to fit?

(3) What length of shank should be allowed to form the head of a rivet for machine riveting?

(4) Explain the difference between a lap joint and a butt joint.

(5) Define the term pitch as applied to rivets.

(6) For a $\frac{1}{2}$-inch plate, what is the minimum thickness for the cover-plates of a butt joint with two cover-plates?

Ans. $\frac{5}{16}$ in.

(7) What precaution in regard to the position of joints should be observed in designing externally fired boilers?

(8) Is it customary to have inside laps face upwards or downwards, and why?

(9) What can you say as to the relative merits of punching and drilling rivet holes?

(10) What is calking and why is it done?

(11) Which must be made the stronger in a boiler, the transverse or the longitudinal joints, and why?

(12) What is meant by the efficiency of a joint, and how is it expressed?

(13) What is generally accepted as a safe ratio of working pressure to bursting pressure?

(14) What working pressure would you allow in a 54-inch boiler constructed of $\frac{3}{8}$-inch steel plate whose tensile strength is 50,000 pounds per square inch, allowing a ratio of safe working pressure to bursting pressure of 1 to 5? The longitudinal seam is a double-riveted butt joint with two cover-plates, having an efficiency of 76 per cent.
Ans. 105.55 lb. per sq. in.

(15) In the previous example, at what pressure would the boiler be about to burst? Ans. 527.7 lb. per sq. in.

(16) A 60-inch cylindrical marine boiler built of $\frac{1}{2}$-inch steel plate has a tensile strength of 55,000 pounds per square inch. If the seams are double-riveted, what is the safe working pressure? Ans. 183.3 lb. per sq. in.

(17) For what are crowfoot braces used?

(18) (*a*) How is a gusset stay made? (*b*) What arrangement is made to give warning when a screw staybolt breaks?

(19) How are boiler tubes fastened in the heads?

BOILER FITTINGS.

EXAMINATION QUESTIONS.

(1) What is the purpose of the safety valve and in what three ways is it weighted?

(2) Which kind of safety valve is generally used on the locomotive boiler?

(3) Name one point in favor of the dead-weight safety valve.

(4) If a pipe is connected to the blow-off side of the safety valve, what precaution should be taken to guard against accident?

(5) Is it good practice to have a valve between the boiler and its safety valve?

(6) A dead-weight safety valve is to be on the point of blowing off at 80 pounds pressure, absolute. The area of the valve is 15 square inches. Find the necessary weight.

Ans. 979.5 lb.

(7) A safety valve with a straight parallel lever has the following dimensions: Area of valve, 12 square inches; distance from center line of valve to fulcrum, 4 inches; distance from fulcrum to point where weight acts, 32 inches; weight of weight, 85 pounds; weight of valve and stem, 6 pounds; weight of lever, 15 pounds; total length of lever, 36 inches. At what pressure will the valve blow off?

Ans. 62.79 lb.

(8) Find the weight that must be placed on the lever if the valve is to blow off at 75 pounds and all the other quantities are the same as in question 7. Ans. 103.31 lb.

(9) A safety valve $4\frac{1}{4}$ inches in diameter is to be set to a pressure of 90 pounds per square inch. At what distance from the fulcrum must a weight of 120 pounds be placed when the distance from the fulcrum to the center line of the valve is 4 inches, the weight of the valve and stem is 14 pounds, the weight of the lever is 18 pounds, and its length is 42 inches? The lever is straight and parallel.
Ans. 38.94 in.

(10) What is the shape of the tube in the Bourdon pressure gauge and why is it so shaped?

(11) How is a steam pressure gauge graduated to read?

(12) If the pointer on a vacuum gauge reads 20 inches while the barometer stands at 30 inches, what pressure does that indicate? Ans. 4.9 lb., absolute.

(13) What precaution should be taken in connecting a gauge to a boiler?

(14) In locating the gauge-cocks in a return-tubular boiler, where should the lowest one be placed?

(15) Why is the level of the water in a gauge glass the same as the level of the water in the boiler?

(16) Give a method of testing the water column.

(17) If a water column should be found to be unreliable, what should be done?

(18) Explain how a fusible plug is made and where it should be located in a vertical, flue, and horizontal-return tubular boiler.

(19) What kind of valve would most engineers prefer to use in blow-off pipes?

(20) What advantage has a gate valve over a globe valve?

(21) For what are check-valves used?

(22) What is the purpose of the dome on a boiler?

(23) Where is the dry pipe located?

(24) What shape are manholes and handholes made? Why?

(25) How are the majority of water alarms operated?

(26) What point should be observed in the arrangement of suction pipes of the feeding apparatus?

(27) What care should be taken in arranging for the discharge of feedwater into the boiler?

(28) What is the common ratio of the combined area of the supports in a grate to the combined area of the air spaces?

(29) What is the objection to stationary grate bars?

(30) What is the purpose of the bridge?

(31) How does a damper regulator control the steam pressure?

COMBUSTION, FIRING, AND DRAFT.

EXAMINATION QUESTIONS.

(1) Define (*a*) element; (*b*) compound; (*c*) mixture.

(2) What is the relation between the volumes of gases and the number of molecules they contain ?

(3) What is the atomic weight of a substance ?

(4) What is combustion ?

(5) (*a*) When carbon and oxygen are brought together under the influence of heat and there is a sufficient supply of oxygen, what is formed ? (*b*) What happens if the supply of oxygen is insufficient ?

(6) What is the principal element in the composition of all fuels ?

(7) How many pounds of water at 212° can be evaporated into steam at the same temperature by a pound of coal of the following composition: carbon 74 per cent., hydrogen 8 per cent., oxygen 5 per cent., and ash 13 per cent. ?

Ans. 16.32 lb.

(8) Why is it desirable to keep the temperature in the furnace as high as possible ?

(9) How may anthracite coal be distinguished from semi-anthracite ?

(10) How do the different proportions of fixed carbon and volatile hydrocarbons vary in the different classes of coal ?

(11) What is the distinguishing feature of caking coal ?

(12) What is coke ?

e a short explanation of coking, spreading, and alternate firing.

(14) What is the cause of gas explosions in the furnace and how may they be avoided?

(15) By what means is air supplied to a furnace?

(16) Explain how a chimney causes a draft.

(17) How is the pressure due to the draft measured?

(18) How is artificial draft produced?

(19) What is the difference between forced draft and induced draft?

(20) How does the cost of fan blowers and steam jets compare?

(21) What are some of the advantages of mechanical draft?

A KEY

TO ALL THE

QUESTIONS AND EXAMPLES

INCLUDED IN THE

EXAMINATION QUESTIONS IN THIS VOLUME.

It will be noticed that the Key is divided into sections which correspond to the sections in the Examination Questions in this Volume. The answers and solutions are so numbered as to be similar to the numbers before the questions to which they refer.

ELEMENTS OF ELECTRICITY AND MAGNETISM.

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(1) The end *b*; because in looking at that end the current circulates around the helix in an opposite direction to the hands of a watch. See Art. **29.**

(2) (*a*) Negative. See Art. **7.**
(*b*) Negative. See Art. **7.**

(3) Let A represent the first branch and B the second; then $r_1 = 16.2$ ohms, $r_2 = 14.1$ ohms, and $C = 6.37$ amperes.

The current c_1 in branch A is found by using formula **10**; substituting gives

$$c_1 = \frac{C r_2}{r_1 + r_2} = \frac{6.37 \times 14.1}{16.2 + 14.1} = 2.9643 \text{ amperes. Ans.}$$

The current c_2 in branch B is found by using formula **11**; substituting gives

$$c_2 = \frac{C r_1}{r_1 + r_2} = \frac{6.37 \times 16.2}{16.2 + 14.1} = 3.4057 \text{ amperes. Ans.}$$

(4) (*a*) From Art. **64** and formula **6**, $C = \frac{E}{R}$, where C is the current in amperes, E is the difference of potential in volts between two points, and R is the resistance in ohms between them. In this example, $E = 58.4$ volts and $R = 2.3$ ohms; hence, $C = \frac{E}{R} = \frac{58.4}{2.3} = 25.3913$ amperes. Ans.

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(*b*) From formula **21**, $W = \frac{E^2}{R}$, where W is the power in watts, E is the E. M. F., or difference of potential in volts, and R is the resistance in ohms. In this example, $E = 58.4$ volts and $R = 2.3$ ohms; hence,

$$W = \frac{E^2}{R} = \frac{58.4^2}{2.3} = \frac{3,410.56}{2.3} = 1,482.8521 \text{ watts.} \quad \text{Ans.}$$

(*c*) By formula **22**, $\text{H. P.} = \frac{W}{746}$; by formula **21**, $W = \frac{E^2}{R}$; therefore (see Art. **81**), $\text{H. P.} = \frac{E^2}{746\,R}$, where H. P. is the horsepower, E the E. M. F., or difference of potential in volts, and R the resistance in ohms.

$$\text{Hence, H. P.} = \frac{58.4^2}{746 \times 2.3} = \frac{3,410.56}{1,715.8} = 1.9877 \text{ horsepower.} \quad \text{Ans.}$$

(5) By formula **8**, $E = C\,R$, where E is the total E. M. F. in volts developed in a closed circuit, C is the current in amperes that is flowing, and R is the total resistance in ohms of the circuit. In this example, $C = .75$ ampere and $R = 17.2 + 8.2 + 11.3 = 36.7$ ohms; hence, $E = C\,R = .75 \times 36.7 = 27.525$ volts, the total E. M. F. developed in the battery.

By derivation from formula **8**, $E' = C\,R'$, where E' is the difference of potential in volts between two points, C is the current in amperes flowing, and R' is the resistance in ohms between the two points.

Between *a* and *b*, $R' = 11.3$ ohms and $C = .75$ ampere; hence, $E' = C\,R' = .75 \times 11.3 = 8.475$ volts. Ans.

Between *b* and *c*, $R' = 8.2$ ohms and $C = .75$ ampere; hence, $E' = C\,R' = .75 \times 8.2 = 6.15$ volts. Ans.

Between *a* and *c*, the difference of potential is the difference of potential between *a* and *b* plus that between *b* and *c*, which is $8.475 + 6.15 = 14.625$ volts. Or, since the difference of potential between *a* and *c* is the available E. M. F. of the battery, when a current of .75 ampere is flowing, it can be calculated by using formula **9**, $E' = E - C r_i$, where E' is the available E. M. F., E is the total E. M. F. developed in the battery, C is the current that is flowing, and r_i is the internal resistance of the battery. In this case, $E = 27.525$ volts, $C = .75$ ampere, and $r_i = 17.2$ ohms; hence, $E' = E - C r_i = 27.525 - (.75 \times 17.2) = 14.625$ volts. Ans.

(6) By formula **8**, $E = C R$, where E is the total E. M. F. in volts developed in a closed circuit, C is the current in amperes flowing, and R is the total resistance in ohms of the circuit. In this example, $C = .127$ ampere and $R = 36.2 + 21.7 = 57.9$ ohms. Hence, by substituting, $E = C R = .127 \times 57.9 = 7.3533$ volts. Ans.

(7) By formula **14**, $Q = C t$, where Q is the quantity of electricity in coulombs that passes through a circuit, C is the current in amperes flowing in that circuit, and t is the time in seconds during which the current flows. In this example, $C = 8.32$ amperes and $t = 2.25 \times 60 \times 60 = 8{,}100$ seconds. Hence, by substituting, $Q = C t = 8.32 \times 8{,}100 = 67{,}392$ coulombs. Ans.

(8) By formula **19**, $W = C E$, where W is the power in watts, E is the E. M. F. in volts, and C is the current in amperes. In this example, $E = 112.5$ volts and $C = 12.2$ amperes. Hence, by substituting, $W = C E = 12.2 \times 112.5 = 1{,}372.5$ watts. Ans.

(9) By formula **4**, $r_2 = r_1 (1 + t k)$, where r_1 is the original resistance of a conductor, r_2 is the resistance after a rise in temperature, k is the temperature coefficient, and t is the rise of temperature in degrees F. In this example, $r_1 = 43.2$ ohms, $t = 85 - 60 = 25°$ F., and $k = .002155$, from Table I. Hence, $r_2 = r_1 (1 + t k) = 43.2 (1 + 25 \times .002155) = 43.2 \times 1.053875 = 45.5274$ ohms. Ans.

(10) By formula **13**, the joint resistance of three conductors in parallel $R''' = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}$, where r_1, r_2, and r_3 are the separate resistance of the three conductors,

respectively. In this example, let $r_1 = 37$ ohms, the resistance of A; $r_2 = 45$ ohms, the resistance of B; and $r_3 = 72$ ohms, the resistance of C. Substituting gives

$$\frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2} = \frac{37 \times 45 \times 72}{45 \times 72 + 37 \times 72 + 37 \times 45} = \frac{119{,}880}{7{,}569}$$

$= 15.8383$ ohms, the joint resistance of the three conductors A, B, and C connected in parallel. Ans.

(11) From Art. **43**, the joint resistance of several conductors connected in series is equal to the sum of their separate resistances; hence, in this example the joint resistance of the four conductors A, B, C, and D in series is $3 + 19 + 72 + 111 = 205$ ohms. Ans.

(12) We here use formula **16**, $J = C^2 R t$, where J is the work in joules, C is the current in amperes, R is the resistance in ohms, and t is the time in seconds. In this case $C = 14.2$ amperes, $R = 8$ ohms, $t = 4{,}500$ seconds. Then, the work done $= 14.2 \times 14.2 \times 8 \times 4{,}500 = 7{,}259{,}040$ joules. Ans.

(13) From Art. **75**, the separate resistance of any branch of a derived circuit is equal to the difference of potential between where all the branches divide and where they unite, divided by the current in that branch.

Hence, the separate resistance of branch A is $\frac{11.6}{6.7} = 1.7313$ ohms. Ans.

The separate resistance of branch B is $\frac{11.6}{4.9} = 2.3673$ ohms. Ans.

(14) By formula **7**, $R = \frac{E}{C}$, where R is the total resistance in ohms of a closed circuit, E is the total E. M. F. in volts developed in the circuit, and C is the current in amperes flowing in the circuit. In this example, $E = 22.4$ volts, and $C = .43$ ampere; hence, $R = \frac{E}{C} = \frac{22.4}{.43} = 52.093$ ohms, the total resistance of the circuit. Since the total resistance of a closed circuit is equal to the sum of

external and internal resistances, the external resist-ce must be the difference between the total resistance d the internal resistance. Hence, the external resistance 52.093 − 13.4 = 38.693 ohms. Ans.

(15) By transposition of terms in formula **14**, $C = \frac{Q}{t}$, here C is the current in amperes, Q is the quantity of lectricity in coulombs, and t is the time in seconds. In his example, $Q = 368{,}422$ coulombs and $t = 4.5 \times 60 \times 60 = 16{,}200$ seconds; hence, $C = \frac{Q}{t} = \frac{368{,}422}{16{,}200} = 22.7421$ amperes. Ans.

(16) By formula **16**, $J = C^2 R t$, where J is the work done in joules, C is the current in amperes, R is the resistance in ohms, and t is the time in seconds. In this example, $C = 2.4$ amperes, $R = 45$ ohms, $t = 3{,}000$ seconds. Then the electrical work done $= 2.4 \times 2.4 \times 45 \times 3{,}000 = 777{,}600$ joules. By formula **18**, the mechanical work done = F. P. $= .7373\,J = .7373 \times 777{,}600 = 573{,}324.48$ foot-pounds. Ans.

(17) By formula **22**, H. P. $= \frac{W}{746}$; by formula **19**, $W = C E$; therefore (see Art. **81**), H. P. $= \frac{E C}{746}$, where H. P. is the horsepower, E is the E. M. F. in volts, and C is the current in amperes. In this example, $E = 525$ volts, and $C = 12.5$ amperes; hence,

$$\text{H. P.} = \frac{E C}{746} = \frac{525 \times 12.5}{746} = 8.7969 \text{ horsepower. Ans.}$$

(18) (*a*) By formula **20**, $W = C^2 R$, where W is the power in watts, C is the current in amperes, and R is the resistance in ohms. In this example, $C = 110$ amperes and $R = 4.2$ ohms; hence, $W = C^2 R = 110^2 \times 4.2 = 50{,}820$ watts. Ans.

(*b*) $\text{H. P.} = \frac{W}{746} = \frac{50{,}820}{746} = 68.123$ horsepower. Ans.

(19) By formula **1**, the changed resistance for variation in length, $r_2 = \frac{r_1 l_2}{l_1}$, where r_1 is the original resistance, l_1 is the original length, and l_2 is the changed length. In this case, $r_1 = 1$ ohm, $l_1 = 1{,}000$ feet, and $l_2 = 2{,}000$ feet. Then, the changed resistance $r_2 = \frac{1 \times 2{,}000}{1{,}000} = 2$ ohms. The next operation is to determine the resistance of the wire when its sectional area is changed. A round wire 1 inch in diameter has a sectional area of $.1^2 \times .7854 = .007854$ square inch, and a square wire .1 inch on a side has a sectional area of $.1 \times .1 = .01$ square inch. By formula **2**, $r_2 = \frac{r_1 a_1}{a_2}$, where r_1 is the original resistance of a conductor, r_2 is the resistance after its sectional area is changed, a_1 is the original sectional area, and a_2 is the changed sectional area. At this stage of the example, $r_1 = 2$ ohms, $a_1 = .007854$ square inch, and $a_2 = .01$ square inch. Hence, $r_2 = \frac{r_1 a_1}{a_2} = \frac{2 \times .007854}{.01} = 1.5708$ ohms. Ans.

(20) By formula **22**, H. P. $= \frac{W}{746}$, where H. P. is the horsepower and W is the power in watts. In this example, $W = 54{,}200$ watts; hence, H. P. $= \frac{W}{746} = \frac{54{,}200}{746} = 72.6541$ horsepower. Ans.

(21) The sectional area of a round column .04 inch in diameter is $.04^2 \times .7854 = .00125664$ square inch, or .001257 square inch, nearly.

Reduce the specific resistance in microhms to the resistance in ohms by dividing by 1,000,000, Art. **44**, which gives $\frac{37.15}{1{,}000{,}000} = .00003715$ ohm; or, in other words, the resistance of a quantity of mercury 1 inch long and whose sectional area is 1 square inch is .00003715 ohm. Next, from this resistance and length, calculate the resistance of a column of mercury 72.3 inches high, with a sectional area of 1 square inch, by using formula **1**, $r_2 = \frac{r_1 l_2}{l_1}$, where r_1 is the original resistance of a conductor, r_2 is the resistance after its length has been changed, l_1 is its original length, and l_2 is its changed length. In this example, $r_1 = .00003715$ ohm, $l_1 = 1$ inch, and $l_2 = 72.3$ inches. Hence, $r_2 = \frac{r_1 l_2}{l_1} = \frac{.00003715 \times 72.3}{1} = .002685945$, or .002686 ohm, nearly; or, in other words, the resistance of a column of mercury 72.3 inches high, having a sectional area of 1 square inch, is .002686 ohm. From this result calculate the resistance of the column when its sectional area is .001257 square inch, by using formula **2**, $r_2 = \frac{r_1 a_1}{a_2}$, where r_1 is the original resistance, r_2 is the resistance after the sectional area has been changed, a_1 is the original sectional area, and a_2 is the changed sectional area. At this stage of the example, $r_1 = .002686$ ohm, $a_1 = 1$ square inch, and $a_2 = .001257$ square inch. Hence,

$$r_2 = \frac{r_1 a_1}{a_2} = \frac{.002686 \times 1}{.001257} = 2.1368 \text{ ohms. Ans.}$$

(22) By formula **6**, $C = \frac{E}{R}$, where C is the current in amperes flowing in a closed circuit, E is the total E. M. F. in volts generated, and R is the total resistance in ohms of the circuit. Since the total resistance of a closed circuit is the sum of the external and internal circuits, $R = 33 + 30 = 63$ ohms, and $E = 45$ volts; hence, $C = \frac{E}{R} = \frac{45}{63} = .7143$ ampere. Ans.

(23) By formula **19**, $W = CE$, where W is the power in watts, E is the E. M. F., or difference of potential in volts, and C is the current in amperes. In this example, $E = 510$ volts and $C = 24.3$ amperes; hence, $W = 510 \times 24.3 = 12,393$ watts. Ans.

(24) Referring to Art. **56,** the total E. M. F. developed by connecting several cells in series is equal to the E. M. F. of one cell multiplied by the number of cells; hence, the E. M. F. of one of the groups of 6 cells is 6 × 1.5 = 9 volts. In the same article it is stated that connecting cells in multiple, or parallel, does not change the E. M. F. between the main conductors. In this case each group of 6 cells can be considered as one large cell developing an E. M. F. of 9 volts, and, consequently, the E. M. F. of the four groups connected in multiple, or parallel, is 9 volts, which would be the E. M. F. indicated by a voltmeter, connected to the main conductors *c* and *c′*. Ans.

(25) By formula **22,** H. P. $= \frac{W}{746}$; by formula **19,** $W = CE$; therefore (see Art. **81**), H. P. $= \frac{EC}{746}$, where H. P. is the horsepower, E is the E. M. F. in volts, and C is the current in amperes. In this example, $E = 250$ volts and $C = 65.7$ amperes; hence, H. P. $= \frac{EC}{746} = \frac{250 \times 65.7}{746} = \frac{16,425}{746}$ = 22.0174 horsepower. Ans.

(26) End *a*; since, Art. **29,** in looking at the face of the end *a*, the current circulates around the core in the same direction as the movement of the hands of a watch.

(27) From Art. **21,** iron and its alloys, nickel, cobalt, manganese, oxygen, cerium, and chromium.

(28) Toward the south pole, since, from Art. **20,** unlike poles attract one another.

(29) Toward the north pole, since, from Art. **20,** unlike poles attract one another.

(30) The current should enter the wire at the end *b*; since, Art. **29,** in looking at the face of the south pole of the magnet, the current should circulate around the core in the direction of motion of the hands of a watch.

(31) By formula **1**, $r_2 = \frac{r_1 l_2}{l_1}$, where r_1 is the original resistance of a conductor, r_2 is the resistance after its length has been changed, l_1 is the original length, and l_2 is its changed length. In this example, $r_1 = 100.8$ ohms, $l_1 = (112 \times 12) + 6 = 1,350$ inches, $l_2 = 11.7$ inches. Hence,

$$r_2 = \frac{r_1 l_2}{l_1} = \frac{100.8 \times 11.7}{1,350} = .8736 \text{ ohm.} \quad \text{Ans.}$$

(32) By formula **4**, $r_2 = r_1 (1 + t k)$, where r_1 is the original resistance of a conductor, r_2 is the resistance after its temperature has risen, k is the temperature coefficient, and t is the number of degrees rise Fahrenheit. In this example, $r_1 = 91.8$ ohms, $t = 72 - 45 = 27°$, and $k = .000244$, from Table I. Hence, $r_2 = r_1 (1 + t k) = 91.8 (1 + 27 \times .000244) = 91.8 \times 1.006588 = 92.4048$ ohms. Ans.

(33) By formula **5**, $r_2 = \frac{r_1}{1 + t k}$, where r_1 is the original resistance of a conductor, r_2 is the resistance after its temperature has fallen, t is the number of degrees fall Fahrenheit, and k is the temperature coefficient of the material. In this example, $r_1 = .144$ ohm, $t = 87 - 41 = 46°$ F., and $k = .002155$, from Table I. Hence,

$$r_2 = \frac{r_1}{1 + t k} = \frac{.144}{1 + 46 \times .002155} = \frac{.144}{1.09913} = .131 \text{ ohm.} \quad \text{Ans.}$$

(34) From Art. **53**, the fundamental equation of the Wheatstone's bridge is $X = \frac{M}{N} \times P$, where X is the unknown resistance, M is the resistance of the upper balance arm, N is the resistance of the lower balance arm, and P is the resistance of the adjustable arm. It will be seen from the connections of the battery and galvanometer circuits in the diagram that the coils lying between c and a form the upper balance arm of the bridge, and, hence, in this example, $M = 1$ ohm; the coils between a and d form the lower balance arm, and, hence, $N = 100$ ohms; the coils between

d and b form the adjustable arm, and, hence, $P = 500 + 200 + 20 + 2 + 1 = 723$ ohms. Substituting these values in the fundamental equation gives

$$X = \frac{M}{N} \times P = \frac{1}{100} \times 723 = 7.23 \text{ ohms. Ans.}$$

(35) By formula **6**, $C = \frac{E}{R}$, where C is the current in amperes flowing in a closed circuit, E is the total E. M. F. in volts developed in the circuit, and R is the total resistance in ohms of the circuit. In this example, $E = 36$ volts and $R = 24 + 18 = 42$ ohms; since, according to Art. **60**, the total resistance of a closed circuit is the sum of the internal and external resistances. Hence, $C = \frac{E}{R} = \frac{36}{42} = .8571$ ampere. Ans.

(36) By formula **7**, $R = \frac{E}{C}$, where R is the total resistance in ohms of a closed circuit, E is the total E. M. F. in volts developed in the circuit, and C is the current in amperes flowing through the circuit. In this example, $E = 12.6$ volts and $C = 2.7$ amperes; hence, $R = \frac{E}{C} = \frac{12.6}{2.7} = 4.6667$ ohms. Ans.

(37) By formula **8**, $E = CR$, where E is the total E.M.F. in volts developed in a closed circuit, C is the current in amperes flowing through the circuit, and R is the total resistance of the circuit. In this example, $C = .8$ ampere and $R = 31.5 + 11 = 42.5$ ohms, since, Art. **60**, the total resistance of a closed circuit is the sum of the internal and external resistances. Hence, $E = CR = .8 \times 42.5 = 34$ volts. Ans.

(38) (*a*) By formula **7**, $R = \frac{E}{C}$, where R is the total resistance in ohms between two points in a circuit, E is the drop or loss of potential in volts between the two points, and C is the current in amperes flowing in the circuit. In

this example, the two conductors leading to and from the receptive device can be considered as in series, forming one single conductor 1,200 feet in length, in which the drop or loss of potential is 10 per cent. of 250 volts, or $.10 \times 250 = 25$ volts; that is, $E = 25$ volts. Since $C = 80$ amperes, then, $R = \frac{E}{C} = \frac{25}{80} = .3125$ ohm; or, in other words, the sum of the resistances of two conductors that transmit a current of 80 amperes to and from the receptive device with a loss of 25 volts is .3125 ohm. Ans.

(*b*) The resistance per foot of any conductor is found by dividing its total resistance by its length in feet. Assume the two conductors leading to and from the receptive device to be one single conductor 1,200 feet in length and offering a resistance of .3125 ohm; hence, its resistance per foot is

$$\frac{.3125}{1,200} = .00026 \text{ ohm. Ans.}$$

(39) By formula **6**, $C = \frac{E}{R}$, where C is the current in amperes flowing in a closed circuit, E is the total E. M. F. in volts developed in the circuit, and R is the total resistance in ohms of the circuit. In this example, $E = 24$ volts and $R = 8.1 + 15.9 = 24$ ohms, since, Art. **60**, the total resistance of a closed circuit is the sum of the internal and external resistances. Hence,

$$C = \frac{E}{R} = \frac{24}{24} = 1 \text{ ampere.}$$

By formula **9**, $E' = E - C r_i$, where E' is the available, or external, E. M. F. in volts of a battery or other electric source in a closed circuit, E is the total E. M. F. in volts developed in the source, C is the current in amperes flowing through the circuit, and r_i is the internal resistance of the battery or electric source. In this example, $E = 24$ volts, $C = 1$ ampere, and $r_i = 8.1$ ohms. Hence, $E' = E - C r_i = 24 - (8.1 \times 1) = 15.9$ volts. Ans.

(40) Let A represent the first branch and B the second; then $r_1 = 1.2$ ohms, $r_2 = 2.2$ ohms, and $C = 45$ amperes.

The current c_1 in branch A will then be found by substituting these values in formula **10,** which gives

$$c_1 = \frac{C r_2}{r_1 + r_2} = \frac{45 \times 2.2}{1.2 + 2.2} = \frac{99}{3.4} = 29.1176 \text{ amperes. Ans.}$$

Since the sum of the currents in the two branches is 45 amperes, the current in branch B is, therefore, the difference between 45 amperes and the current in branch A, or $45 - 29.1176 = 15.8824$ amperes. Ans.

(41) (*a*) A kilowatt is 1,000 watts or about $1\frac{1}{3}$ horsepower.

(*b*) 150 kilowatt = 150,000 watts. By formula **22,**

$$\text{H. P.} = \frac{150{,}000}{746} = 201.072 \text{ horsepower. Ans.}$$

(42) 300 kilowatt = 300,000 watts. By transposing formula **19,** we get

$$C = \frac{W}{E} = \frac{300{,}000}{250} = 1{,}200 \text{ amperes. Ans.}$$

(43) (*a*) A kilowatt-hour is a unit of electrical work and is equal to the total amount of work done when one kilowatt is supplied for one hour.

(*b*) 110 volts × 40 amperes = 4,400 watts. $\frac{4400}{1000} = 4.4$ kilowatts. The time is 9.5 hours. The kilowatt-hours = 4.4×9.5, or 41.8 kilowatt-hours. Ans. See Art. **83.**

DYNAMOS AND MOTORS.

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(1) By formula **1,** $E = \frac{2\,N\,S\,n}{10^8}$. In this example, $N = 6{,}250{,}000$ lines of force, $S = 100$ outside, or face, wires in series, for if 200 turns were wound around the core, there would be 200 outside, or face, wires and from Art. **23** one-half would be connected in series, and $n = \frac{1{,}200}{60}$ revolutions per second. Substituting these values in above formula gives $E = \frac{2\,N\,S\,n}{10^8} = \frac{2 \times 6{,}250{,}000 \times 100 \times 1{,}200}{100{,}000{,}000 \times 60}$ $= 250$ volts. Ans.

(2) From Art. **36,** it will be seen that the current in the shunt field of a dynamo is equal to the difference of potential between the brushes divided by the resistance of the shunt field circuit, or $C_s = \frac{E}{R_s}$. In this example, $E = 220$ volts and $R_s = 440$ ohms; hence, $C_s = \frac{E}{R_s} = \frac{220}{440} = .5$ ampere. Ans.

(3) An alternating current is one that is continually reversing in direction in a regular periodic manner, flowing first in one direction in a circuit and then in the other, while a continuous current is one that flows, without stopping, in one direction. See Arts. **13** and **14.**

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(4) In Art. 1, it is stated that a current will be induced in a closed coil or circuit when there is a change in the number of lines of force passing through that coil or circuit. In this case, as the magnetic field is uniform, there is no change in the total number of lines of force passing through, or enclosed by, the coil C when it is moved from its original position to the position C', as shown by the dotted outlines; and, hence, no current will flow around the ring.

(5) In this example, it is first necessary to determine the input in watts. By formula 4, the input $I = \frac{100 \times 17{,}500}{87.5}$ $= 20{,}000$ watts. Since 2.6 per cent. of the input is used to excite the field magnets and the input is 20,000 watts, then the watts consumed in exciting the field magnets will be 2.6 per cent. of 20,000 watts; hence, as in Art. 64, the field loss $= \frac{20{,}000 \times 2.6}{100} = 520$ watts. Ans.

(6) In Art. **67**, $C_s = \frac{E_s}{r_s}$. In this example, $C_s = \frac{110}{55}$ $= 2$ amperes. The watts lost in the shunt circuit are equal to the difference of potential between the terminals of that circuit multiplied by the current in amperes flowing through the circuit; or, $W = E \times C$. Substituting, we have $W = 110 \times 2 = 220$ watts. Ans.

(7) A commutator is usually a cylinder formed of a number of copper bars insulated from one another and running longitudinally or parallel with the axis of the cylinder. Each copper bar is joined to the armature winding at regular intervals and the commutator is fastened to the shaft of the armature so as to rotate with it.

The commutator is used to transform the alternating current that is generated in the armature coils of a dynamo so that a continuous current may be obtained in the circuit external to the armature, or conversely to transform a continuous current that flows in an external circuit into an alternating current as it passes into the winding of a motor armature. See Arts. **14** and **19**.

(8) Use formula **4.** In this example, the input $= \frac{100 \times 65,000}{90.5} = 71,823.2$ watts. Since 1 horsepower equals 746 watts, then 71,823.2 watts equal $\frac{71,823.2}{746} = 96.28$ H. P. Ans.

(9) If the current circulates in the direction indicated by the arrowheads, *neither* pole piece will be a north pole; for it will be seen that the north pole of one field coil is opposite the south pole of the other, and the lines of force circulate around the magnets without passing through the armature. If the winding of the right-hand coil were reversed, its top would be a north pole, and the top of the left-hand coil being also north, the pole piece P would become a north consequent pole and P' a south consequent pole.

(10) In this example, it is first necessary to change the input from horsepower to watts. Since 1 horsepower is equivalent to 746 watts, then 10 horsepower are equivalent to 10 × 746 = 7,460 watts. Then, by formula **2,** the efficiency $\mathbf{E} = \frac{100 \times 6,341}{7,460} = 85$ per cent. Ans.

(11) From b to a through the conductor; for, by applying the thumb-and-finger rule given in Art. **8** as indicated, it will be seen that the middle finger is pointing toward a from b.

(12) In this example, it is first necessary to find the input in watts. In this example, the output = 11,900 watts and the per cent. efficiency = 85. Then, by formula **4,** the input $= \frac{100 \times 11,900}{85} = 14,000$ watts input. As in Art. **64,** the watts lost are found by multiplying the input by the percentage of loss and dividing by 100. Hence, $\frac{14,000 \times 1.8}{100} = 252$ watts lost in core by eddy currents and hysteresis. Ans.

(13) (*a*) When a current is being generated in the armature of a dynamo, the reaction between this current and the

lines of force produced by the field oppose the rotation of the armature conductors, in fact, it tends to rotate the armature in the opposite direction. This opposing effect of the current in the armature of a dynamo is known as the counter torque of a dynamo. See Art. 28.

(*b*) If a conductor is forcibly moved, as in a dynamo armature, across a magnetic field in a given direction, say in the direction of the arrows *a*, *a*, Fig. 33, a current will flow in the conductor from *c* to *c'*. If this same conductor is not forcibly moved, but lies in this same field, and a current is sent through it in the same direction as before, that is from *c* to *c'*, then the conductor will move across the field in the direction of the arrows *b*, *b*, if there is nothing to oppose its motion. The force causing this latter motion evidently will oppose the force producing the motion of the conductor in the dynamo armature. These two opposing forces are evidently present in a dynamo armature, the counter torque being the smaller, of course, else the armature would not revolve. See Art. 25.

(14) $W = C^2 r$. In this example, $C = 120$ amperes and $r = .040$ ohm; hence, $W = 120^2 \times .040 = 576$ watts. Ans.

(15) Under "Field Losses," in Art. 66, the watts lost in the series coils is found by using the formula $W = C^2 R$. In this example, $C = 40$ amperes and $R = .04$ ohm; hence, $W = 40^2 \times .04 = 40 \times 40 \times .04 = 64$ watts, which represents the loss in the series coils. The watts lost in the shunt coil is given by the formula $W = \frac{E^2}{R}$. In this case, $E = 550$ volts and $R = 550$ ohms; hence, $W = \frac{E^2}{R} = \frac{550 \times 550}{550} = 550$ watts, which is the loss in the shunt field. The total loss in the fields of a compound-wound dynamo is equal to the sum of the losses in the series and shunt coils. Hence, the total loss in this case is $64 + 550 = 614$ watts. Ans.

(16) When current flows in the armature conductors, the armature core is magnetized by this current in such a

direction as will produce lines of force exactly at right angles to the lines of force produced by the field, if the two magnetizing forces could act independently of each other. But lines of force cannot cross each other, hence the two systems of lines of force rearrange themselves and produce, as a result, neutral points that are shifted forwards, in the case of a dynamo, in the direction of rotation when current flows or increases in strength in the armature conductors. See Art. **29.**

(17) From Art. **63,** the total loss in a dynamo is the sum of the separate losses; hence, in this example, the total loss in watts is $356 + 178 + 263 + 423 + 50 = 1{,}270$ watts. From Art. **59,** the input to the dynamo in this case is $15{,}000 + 1{,}270 = 16{,}270$ watts. By formula **2,** the efficiency $E = \frac{100 \times 15{,}000}{16{,}270}$, or 92.19 per cent. at this output. Ans.

(18) From example 17, the loss in mechanical friction is 356 watts, and the input is 16,270 watts; hence (see Art. **72**), the percentage loss is $\frac{356 \times 100}{16{,}270}$, or 2.1881 per cent. Ans.

From example 17, the loss in the core by eddy currents and hysteresis is 178 watts, and the input is 16,270 watts; hence, the percentage of loss is $\frac{178 \times 100}{16{,}270}$, or 1.094 per cent. Ans.

From example 17, the loss in the field coils is 263 watts, and the input is 16,270 watts; hence, the percentage of loss is $\frac{263 \times 100}{16{,}270}$, or 1.6165 per cent. Ans.

From example 17, the loss in the armature ($C^2 r$) $= 423$ watts, and the input is 16,270 watts; hence, the percentage of loss is $\frac{423 \times 100}{16{,}270}$, or 2.5999 per cent. Ans.

From example 17, the sum of the separate losses is 1,270 watts, and this is the difference between the input and the output; the input is 16,270 watts; then, by formula **3,** the total percentage of loss $L = \frac{100 \times 1{,}270}{16{,}270}$, or 7.8058 per cent. Ans.

(19) From Art. **22**, it will be seen that the electromotive force generated in an armature is proportional to the speed, other conditions and quantities remaining unchanged. Hence, in this example, if E represents the electromotive force that is generated when the armature is driven at 1,400 revolutions per minute, then, by proportion, $440 : E :: 1,200 : 1,400$, or $E \times 1,200 = 440 \times 1,400$; therefore, $E = \frac{440 \times 1,400}{1,200} = 513\frac{1}{3}$ volts. Ans.

(20) They spark less than copper brushes, especially when the load is a variable one. See Art. **79.**

(21) Yes; because, Art. **1**, a change takes place in number of lines that pass through the coil. From the rule given in Art. **7**, it will be seen that the current will circulate around the ring in the same direction as the movements of the hands of a watch; for the effect of the motion is to diminish the number of lines of force that pass through the coil, and the observer is looking along the magnetic field in the direction of the lines of force.

(22) See Art. **42.**

(23) The *rate of cutting* lines of force is found by dividing the number cut by the time required to cut them; hence, in this case, the rate of cutting is $\frac{8,000,000}{.25} = 32,000,000$ lines of force per second.

(24) Because the solid iron core would act as a large conductor cutting lines of force, thereby producing *local*, or *eddy*, currents in the core, heating it badly, and uselessly dissipating a large amount of energy. See Art. **16.**

(25) From Art. **22**, it will be seen that the electromotive force generated in an armature is proportional to the number of lines of force passing through the core. Let E represent the electromotive force that is generated when 1,250,000 lines of force are passing through the core; then, by proportion, $200 : E :: 750,000 : 1,250,000$, or

$E \times 750{,}000 = 200 \times 1{,}250{,}000$; therefore, $E = \frac{200 \times 1{,}250{,}000}{750{,}000}$ $= 333\frac{1}{3}$ volts. Ans.

(26) (*a*) See Art. **65.**
(*b*) See Art. **70.**
(*c*) See Art. **66.**

(27) Toward the side *a*; for, by applying the thumb-and-finger rule given in Art. **26,** and making the forefinger point in the direction of the lines of force and the middle finger in the direction of the current, the thumb will point toward the side *a*.

(28) Use the formula given under "Field Losses" in Art. **67,** $C_s = \frac{E_e}{r_s}$, which is a modification of the formula $C = \frac{E}{R}$. In this example, $E_e = 525$ volts and $r_s = 650$ ohms; hence, $C_s = \frac{E_e}{r_s} = \frac{525}{650} = .8076$ ampere. Ans.

(29) The increase in voltage from no load to full load is $124.2 - 115 = 9.2$ volts, which is $\frac{9.2 \times 100}{115} = 8$ per cent. of the normal voltage. Therefore, the over-compounding is 8 per cent. Ans.

(30) It is radiated from the surface into the surrounding air, and some of it may be conducted away through the shaft, bearings, and base.

(31) See Arts. **34, 36,** and **39.**

(32) From Art. **72,** the percentage of loss in the core is found by dividing the number of watts lost in the core by the input and multiplying by 100. Reducing 64 horsepower to watts gives $64 \times 746 = 47{,}744$ watts. Consequently, the loss in the core is $\frac{800 \times 100}{47{,}744} = 1.6756$ per cent. Ans.

(33) See Art. **76.**

(34) See Art. **43.**

OPERATION OF DYNAMOS AND MOTORS.

(1) The dust from coal and from the machines mentioned is very injurious to the bearings of engines and electrical machines and also to the commutators and general insulation of the latter. See Art. **1.**

(2) (*a*) Copper brushes are generally used on electric-light dynamos where the current output is large and the voltage low.

(*b*) They are generally set tangential, or approximately so, never radially.

(3) (*a*) Copper brushes are trimmed to fit the commutator by shaping and filing them in an iron jig, properly shaped to fit the surface of the commutator.

(*b*) Carbon brushes are usually made to fit the commutator by putting the brush in position and then drawing a piece of sandpaper (never emery paper) between the brush and the commutator against which the brush-holder spring presses the brush, the sanded side of course being next to the carbon brush.

(4) The odor of hot oil around a machine usually indicates an abnormally hot bearing.

(5) It may be due to the lack of power on the line or an open or short circuit in the field of the machine or in the

(*b*) To remedy a low bar it is usually necessary to turn down, file, or sandpaper the whole commutator to a smooth and true surface.

(12) The commutator becomes rough, the brushes heat and spark, the belt squeaks, and the machine grows hot all over.

(13) Severe sparking is caused and the circuit-breaker opened because the motor armature generates but little counter E. M. F., and forms practically a short circuit across the supply mains. In some cases the motor may speed up excessively.

(14) A rotary converter may be started by connecting the alternating-current side to the line; by supplying the direct-current side with direct current from another rotary or from a storage battery; by starting up the alternator. See Art. **89.**

(15) The other coils become warm. See Art. **41.**

(16) By holding a piece of iron near the armature; the piece of iron will vibrate when the coil passes it. See Art. **23.** Another method is to use the device described in Art. **97.**

(17) (*a*) An unusually large deflection would indicate an open circuit in the armature coil whose terminals are supposed to be connected to the commutator bars upon which the testing clips rest.

(*b*) No deflection would indicate one of three things: either a dead cross in the coil connected to the commutator bars upon which the testing clips rest, or a cross between the two bars themselves, or that there was an open circuit in the same half of the armature in which the testing clips were being used, but somewhere else except between the test clips. A smaller deflection than that given by a good coil would indicate a partially short-circuited coil or poor insulation between the turns or between the commutator bars under the test clips.

(18) (*a*) If the pressure is greater than necessary, the wear on the commutator and the friction to be overcome will be unnecessarily great.

(*b*) If the pressure is too small, there will be sparking and heating because of the bad contact between brush and commutator.

(19) (*a*) Such scratches usually indicate that there are particles of hard foreign matter under one or more of the brushes.

(*b*) The remedy is to remove the brushes and clean them thoroughly.

(20) The brushes will play or bear over the whole wearing surface of the commutator, thus preventing the wearing of the commutator in ruts.

(21) It would indicate that the bearings had worn down or that a field core had become loose, thus allowing the armature to rub against the core or pole piece.

(22) (*a*) In a dynamo, one field coil reversed would reduce the voltage and perhaps render the machine incapable of generating at all.

(*b*) In a motor, one field coil reversed would increase the current required to start the motor, would abnormally increase the speed after it is started, and would cause the brushes to spark. A motor with but two field coils may refuse to start or else start very slowly if one of its field coils is reversed.

(23) All residual magnetism may have disappeared or the field and armature may be improperly connected together. Reversing either the armature or the field, not both, after they were once properly connected, would destroy whatever residual magnetism there may have been and, consequently, the machine would refuse to generate. For other causes and remedies see Arts. **49** to **52,** inclusive.

(24) Ordinary synchronous motors will not start up by themselves under load. They must be brought up to synchronism under no load, either by themselves, by switching on the line current, or by some outside source of power, as, for example, by a small induction motor.

(25) It would indicate that the one armature coil was short-circuited.

(26) A broad scratch around the surface of a commutator indicates that probably one of the brush holders has been set too close or has become loose and slipped down, so that it touches the commutator.

(27) An induction motor is started up by first seeing that the starting compensator, resistance, or other device is in circuit, then throwing in the main switch and cutting out the compensator or resistance as the motor comes up to speed.

HEAT AND STEAM.

(1) It causes a rise in temperature, causes an increase in volume, and causes a body to change from a solid to a liquid or from a liquid to a gas, according to the state it is in when the heat is applied. See Art. **8.**

(2) When we speak of the temperature of a body, we refer to the condition of the molecules that compose it. If they are in a state of rapid vibration, the body is said to have a high temperature; if they are moving slowly, it is said to have a low temperature. See Art. **2.**

(3) (*a*) A British thermal unit is the quantity of heat required to raise 1 pound of water through 1 degree Fahrenheit. See Art. **10.**

(*b*) One B. T. U. is equivalent to 778 foot-pounds of work. See Art. **13.**

(4) If two blocks of wood are rubbed briskly together, they will develop heat. There are many other similar instances. See Art. **12.**

(5) (*a*) and (*b*) See Art. **16.**

(*c*) See Art. **14.**

(6) To raise 10 pounds of water from 74° to 75° requires 10 B. T. U. Then, the specific heat of glass, according to Art. **15,** is the ratio of 1.77 to 10, or .177 equals the specific heat of glass. Ans. See Art. **15.**

(7) Since it takes 1 B. T. U. to raise 1 pound of water through 1 degree of temperature, and when 1 pound of water falls 1 degree of temperature, it gives off 1 B. T. U., 1,000 pounds of water falling 1 degree of temperature will give off 1,000 B. T. U., and falling from 212° to 192°, or 20°, will give off $1,000 \times 20 = 20,000$ B. T. U. Each pound of steam in being transformed into water gives off its latent heat, 966 B. T. U.; 1,000 pounds give off $1,000 \times 966 = 966,000$ B. T. U.; so the whole amount of heat liberated by 1,000 pounds of steam at 212° in being transformed to water at 192° is $966,000 + 20,000 = 986,000$ B. T. U. In order to raise 1 pound of water from 32° to 212°, it takes $212° - 32° = 180$ B. T. U. Therefore, 986,000 B. T. U. will raise $986,000 \div 180 = 5,477.77$ lb. of water from 32° to 212°. Ans.

(8) Applying rule **2**, Art. **19**, the product of the weight, specific heat, and temperature of the water is $10 \times 1 \times 90 = 900$; of the mercury, $15 \times .0333 \times 60 = 29.97$; of the alcohol, $20 \times .60 \times 40 = 480$; and the sum of these products is $900 + 29.97 + 480 = 1,409.97$. The product of the weight and specific heat of the water is $10 \times 1 = 10$; of the mercury, $15 \times .0333 = .4995$; of the alcohol, $20 \times .60 = 12$; and the sum of these products is $10 + .4995 + 12 = 22.4995$. Then the temperature of the mixture is $1,409.97 \div 22.4995 = 62.66°$. See Art. **19.**

(9) The quantity of heat contained in a mixture is the same as the quantity of heat contained in the substances before mixing. See Art. **19.**

(10) Using rule **3**, Art. **20**, and substituting, we have

$$T = \frac{20\,(966 + 212) + 400 \times 55}{20 + 400} = 108.47°. \quad \text{Ans.}$$

(11) The boiling pressure of a liquid varies directly with the pressure on its surface. See Art. **22.**

(12) (*a*) Saturated steam is steam having the temperature corresponding to its pressure. See Art. **23.**

(*b*) Superheated steam is steam that is not in contact with water and is at a temperature higher than the boiling point corresponding to its pressure. See Art. **25.**

(13) See Art. **27.**

(14) According to rule **1,** Art. **15,** the heat required to raise the temperature of 10 pounds of ice from 25° to 32° is $.504 \times 10\,(32 - 25) = 35.28$ B. T. U. It requires 144 B. T. U. to change 1 pound of ice to water at the same temperature. To change 10 pounds of ice at 32° to water at 32° requires, therefore, $10 \times 144 = 1{,}440$ B. T. U. Then, to raise the water from 32° to 212° requires, according to rule **1,** Art. **15,** $1 \times 10\,(212 - 32) = 1{,}800$ B. T. U. To change 1 pound of water into steam at the same temperature requires 966 B. T. U., and to change 10 pounds of water at 212° to steam at 212° requires $10 \times 966 = 9{,}660$ B. T. U. Therefore, to change 10 pounds of ice at 25° to steam at 212° requires

$$\begin{array}{r} 35.28 \\ 1440.00 \\ 1800.00 \\ 9660.00 \\ \hline 12935.28 \end{array}\ \text{B. T. U.}\quad \text{Ans.}$$

(15) See Art. **29.**

(16) 90 pounds gauge pressure $= 90 + 14.7 = 104.7$ pounds absolute pressure. The heat required to change water at the boiling temperature into steam at the same temperature, called the "latent heat of vaporization," is denoted in the table by L. Now, referring to the table, we find that for $p = 104.7$, $L = 881.368$. That is, it takes 881.368 B. T. U. to change 1 pound of water at 90 pounds gauge pressure into steam at the same pressure. To change 40 pounds requires $40 \times 881.368 = 35{,}254.72$ B. T. U. $35{,}254.72 \times 778 = 27{,}428{,}172$ ft.-lb. Ans.

TYPES OF STEAM BOILERS.

(1) Boilers may be divided into three general classes: stationary, locomotive, and marine. See Art. **3.**

(2) See Art. **2.**

(3) Hemispherical heads are used because they do not have to be braced. See Art. **4.**

(4) (*a*) Plain cylindrical boilers are usually hung from girders above them. See Art. **4.**

(*b*) Vertical boilers usually rest on a foundation built in the ground. See Art. **25.**

(5) By a damper in the chimney. See Art. **5.**

(6) The fire-line should always be below the water-line. If the hot gases come into contact with the boiler above the water-line, the boiler will become unduly heated and will be liable to rupture. See Art. **5.**

(7) (*a*) The safety valve is to prevent the steam rising above a certain pressure, by automatically allowing some of it to escape when it reaches that pressure.

(*b*) The steam gauge is to indicate the pressure of the steam within the boiler.

(*c*) The water gauge is to show the height of the water in the boiler. See Art. **5.**

(8) The blow-off pipe is situated in the lowest part of the boiler, so that when it is opened the boiler may be entirely emptied of all water and sediment. See Art. **5.**

(9) In the plain cylindrical boiler, the gases pass from the fire in front, under the boiler, and out to the chimney at the back. In the return-tubular boiler the gases pass from the fire in front, under the boiler, and returning through the tubes to the front, pass out to the chimney. See Arts. **5** and **8.**

(10) In the return-tubular boiler the fire is underneath the shell, while in the Cornish and Lancashire boilers it is inside the shell. See Arts. **8** and **9.**

(11) The chief objection is the liability of the flues to collapse, owing to the steam pressure on the outside of them. They are, however, comparatively economical in the use of fuel. See Art. **12.**

(12) By discharging the exhaust through the smokestack. See Art. **14.**

(13) The Babcock and Wilcox and the Root water-tube boilers have their tubes set at an angle with the horizontal in order to facilitate circulation. See Arts. **19** and **22.**

(14) The mud drum is located in the bottom of the main drum. In this location it is very hot and the heat tends to precipitate the impurities in the water. See Art. **23.**

(15) There are three drums and the tubes are nearly vertical. See Fig. 20, Art. **24.**

(16) The Hazelton is a water-tube boiler and is supported entirely by its own foundation. See Art. **25.**

(17) In the Hazelton boiler, the tubes are short and straight with one end inserted in the upright cylinder and the other end closed. In the Morrin boiler, the tubes are ved and both ends are inserted in the upright cylinder. Arts. **25** and **26.**

) The Cahall is a vertical water-tube boiler. Circu- is brought about by means of an external pipe through n the water flows down, the heat driving it up through internal tubes. See Art. **27.**

(19) The feedwater enters at the lowest point of the boiler. See Art. **28.**

(20) See Art. **30.**

(21) See Arts. **29** and **31.**

(22) Heat is transferred from the fuel to the water by radiation, conduction, and convection. See Art. **35.**

(23) When the circulation is rapid, the heat is transferred to the water much faster and less of it goes up the chimney. Rapid circulation also tends to prevent the deposit of sediment and keeps the different parts of the boiler at a uniform temperature. See Art. **38.**

BOILER DETAILS.

(1) Machine riveting makes a tighter joint than hand riveting, and as a general thing is cheaper. See Art. **3.**

(2) The rivet is generally $\frac{1}{16}$ inch less in diameter than the hole before driving. See Art. **3.**

(3) About $1\frac{1}{4}$ times the diameter of the rivet hole. See Arts. **2** and **3.**

(4) In a lap joint the edges of the plates are lapped over each other and riveted. In a butt joint the edges of the plates are faced off square, brought together, and another plate is put on one or both sides. It is then riveted to the shell on both sides of the joint. See Art. **4.**

(5) The distance from the center of one rivet hole to the center of the next is called the pitch. See Art. **5.**

(6) According to Art. **7,** the thickness should not be less than $\frac{1}{2} \times \frac{5}{8} = \frac{5}{16}$ in. Ans.

(7) In designing externally fired boilers, care should be taken to keep the joints as far as possible from the fire. See Art. **8.**

(8) Inside laps should face downwards so as not to form a ledge for the collection of sediment. See Art. **8.**

(9) Punched holes are cheaper, but do not make as good work as drilled holes. See Art. **10.**

(10) Calking is the operation of driving the edge of the upper plate down close to the lower plate of a joint and is done to form a tight joint. See Art. **11.**

(11) The longitudinal joints must be made stronger than the transverse, as there is about twice as much strain on them. See Art. **13.**

(12) The efficiency of a joint is the ratio of the strength of the joint to that of the solid plate. It is expressed in per cent. of the strength of the solid plate. See Art. **16.**

(13) A safe ratio of working to bursting pressure is 1 to 5. See Art. **19.**

(14) Using rule 3, Art. **19,** and substituting, we get

$$p = \frac{\frac{3}{8} \times 50{,}000 \times 76}{500 \times \frac{54}{2}} = 105.55 \text{ lb. per sq. in. Ans.}$$

(15) Applying rule 2, Art. **18,** we get

$$p = \frac{\frac{3}{8} \times 50{,}000 \times 76}{100 \times \frac{54}{2}} = 527.7 \text{ lb. per sq. in. Ans.}$$

(16) Applying rule 5, Art. **20,** we get

$$p = \frac{\frac{1}{2} \times 55{,}000}{5 \times \frac{60}{2}} = 183.3 \text{ lb. per sq. in. Ans.}$$

(17) Crowfoot braces are used chiefly to support the heads of stationary boilers. See Art. **24.**

(18) (*a*) A gusset stay is made by riveting a plate to two pairs of angle irons riveted, one to the head and one to the shell of the boiler. See Art. **26.**

(*b*) See Arts. **29** and **30.**

(19) Tubes 5 inches in diameter and less are expanded into the holes by a tool made for the purpose. Tubes over 5 inches in diameter are riveted to the heads. See Art. **32.**

BOILER FITTINGS.

(1) The purpose of the safety valve is to prevent the steam pressure from rising above a certain point. See Art. **1.** Safety valves are weighted by (*a*) a dead weight; (*b*) a weight on a lever; (*c*) a spring. See Art. **2.**

(2) Spring safety valves are generally used on locomotive boilers. See Art. **5.**

(3) The dead-weight safety valve is not likely to be overloaded on account of the size of the weight it would require to overload it. See Art. **3.**

(4) It should be amply large and have a drain pipe at its lowest point. See Art. **9.**

(5) No. No obstruction of any kind should ever be placed between a boiler and its safety valve. See Art. **9.**

(6) 80 pounds absolute pressure is equal to $80 - 14.7 = 65.3$ pounds gauge pressure. Now, if the steam exerts a pressure of 65.3 pounds per square inch on 15 square inches, it will exert a total pressure on the valve of $65.3 \times 15 = 979.5$ pounds. Hence, the valve will be on the point of blowing off when the weight is 979.5 lb. Ans.

(7) Using rule 1, Art. **14,** and substituting the values given in the example, we get

$$P = \frac{\frac{85 \times 32}{4} + 73.5}{12} = 62.79 \text{ lb. Ans.}$$

Note.—To find the value of w. The downward pressure due to the weight of the lever is found by multiplying its weight by th distance from the fulcrum to its center of gravity and dividing by t distance from the fulcrum to the center line of the valve. The cer of gravity of a straight parallel lever such as we have here is at its center, or at a distance from the fulcrum equal to half its length. Hence, $\frac{15 \times 18}{4} = 67.5$ pounds equals the downward pressure due to the weight of the lever. The value of w is found by adding this pressure to the weight of the valve and stem, so $w = 67.5 + 6 = 73.5$ pounds.

(8) Using rule **3**, Art. **15**, and substituting, we get

$$W = \frac{(12 \times 75 - 73.5)\,4}{32} = 103.31 \text{ lb.} \quad \text{Ans.}$$

(9) Using rule **2**, Art. **14**, and substituting, we get

$$L = \frac{(4.25^2 \times .7854 \times 90 - 108.5) \times 4}{120} = 38.94 \text{ in.} \quad \text{Ans.}$$

The downward pressure w due to the weight of the lever, valve, and stem is $\frac{18 \times 21}{4} + 14 = 108.5$ lb.

(10) The tube is elliptical in section, so that when the fluid is forced into it under pressure it will tend to become round and straighten out, thus moving the pointer to which it is attached. See Art. **16.**

(11) The dials of pressure gauges are graduated to read pounds pressure per square inch above the pressure of the atmosphere per square inch. See Art. **17.**

(12) It indicates that the pressure in the vessel to which the gauge is attached is equal to 30 inches (atmospheric pressure) − 20 inches = 10 inches of mercury, or that the pressure is 10 × .49 = 4.9 lb. absolute. See Art. **18.**

(13) In connecting a gauge to a boiler, the connecting pipe should be so bent as to protect the spring from excessive heat. Care should be taken to prevent a column of water from pressing on the spring and thus indicating a false pressure. See Art. **20.**

(14) The lowest cock in a return-tubular boiler should be placed about 3 inches above the upper row of tubes. See Art. **27.**

5) Because the lower fitting is connected with the er space and the upper fitting with the steam space. Art. **28.**

(16) See Art. **32.**

(17) The fires should be drawn and the boiler immediately relieved of pressure until the trouble is remedied. See Art. **33.**

(18) See Arts. **36, 37,** and **38.**

(19) Plug cocks packed with asbestos. See Art. **43.**

(20) The fluid can flow through a gate valve with less resistance than through a globe valve. See Art. **49.**

(21) Check-valves are used where it is desirable to have the fluid pass through in one direction and not return. See Art. **50.**

(22) Domes increase the steam space and are believed to allow the steam to become dry. See Art. **54.**

(23) The dry pipe is located inside the boiler near the top of the shell. See Art. **58.**

(24) Manholes and handholes are made elliptical to allow the covers to be put in and removed. See Art. **64.**

(25) By means of floats. See Art. **70.**

(26) Suction pipes should be as short and free from bends as possible and perfectly air-tight. See Art. **77.**

(27) Feedwater should be discharged into the boiler in the form of spray, and it should not be discharged on any part that is very hot. It should be so discharged as to aid the circulation. See Art. **85.**

(28) It is generally about 1 : 1. See Art. **88.**

(29) The furnace doors have to be kept open while the grates are cleaned, allowing cold air to come in contact with the heated shell. See Art. **93.**

(30) The bridge is built for the purpose of keeping the hot gases in contact with the heating surface of the boiler. See Art. **97.**

(31) The damper regulator controls the volume and velocity of the gases passing up the chimney, and this regulates the intensity of fire and the steam pressure. See Art. **98.**

COMBUSTION, FIRING, AND DRAFT.

(1) (*a*) Elements are substances that have never been decomposed into other substances.

(*b*) Compounds are substances that can be decomposed into other substances.

(*c*) A mixture is a substance formed by two or more substances that are in contact with each other, but which do not combine. See Arts. **2**, **3**, and **9**.

(2) Equal volumes of gases at the same pressure and temperature contain equal numbers of molecules. See Art. **5**.

(3) The atomic weight of a substance is the ratio between the weight of an atom of the substance and an atom of hydrogen. See Art. **7**.

(4) Combustion is the chemical combination of oxygen with carbon, or hydrogen, or both. See Art. **10**.

(5) (*a*) When carbon and oxygen are brought together under the influence of heat and there is a sufficient supply of oxygen, carbon dioxide is formed. See Art. **11**.

(*b*) If there is not a sufficient supply of oxygen present, carbon monoxide is formed. See Art. **13**.

(6) The chief element in the composition of all fuels is carbon. See Art. **18**.

(7) The heat of combustion of this coal, according to rule **2**, is $B = 146 \times 74 + 620 \times 8 = 15{,}764$ B. T. U. The

Steam Table shows that it takes 966 B. T. U. to change 1 pound of water at 212° into steam at 212°. Therefore, 15,764 B. T. U. will evaporate 15,764 ÷ 966 = 16.32 lb. Ans. See Art. 16.

(8) A high temperature is conducive to complete combustion and causes the water to take up heat faster than low temperatures. See Art. 17.

(9) Semi-anthracite coal will rub off while anthracite will not do so. See Art. 22.

(10) Anthracite coal contains more fixed carbon and less of the volatile hydrocarbons than any other coal, while bituminous coal contains less fixed carbon and more of the volatile hydrocarbons than any other kind. See Art. 19.

(11) Caking coal, when burned, fuses together in a solid mass. See Art. 24.

(12) Coke is the substance that is left after the volatile hydrocarbons have been driven from bituminous coal. See Art. 27.

(13) See Arts. 35, 36, 37, 38.

(14) Gas explosions are caused by the hydrocarbons becoming mixed with the air in certain proportions and the mixture becoming ignited. They may be avoided by firing light, by alternate firing, and by always leaving some part of the fire uncovered when putting in fresh coal. See Art. 39.

(15) Air is supplied to the furnace by means of a chimney or by means of a fan or blower. See Art. 40.

(16) The draft in a chimney is caused by the difference in temperature of the gases inside and outside of it. See Art. 41.

(17) The pressure due to the draft is measured in inches of water by means of a water gauge. See Art. 43.

(18) Artificial draft is produced by means of steam jets or by mechanically driven fans. See Art. 45.

(19) See Art. **45.**

(20) Fan blowers are more costly to install, but they cost less to operate than steam jets. See Arts. **46** and **53.**

(21) See Arts. **50, 51, 52.**

INDEX.

NOTE.—All items in this index refer first to the section (see the Preface) and then to the page of the section. Thus, "Alternators 10 56" means that alternators will be found on page 56 of section 10.

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